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SCS ENGINEERS LONG BEACH CA JUN 82 NCEL-CR-82.001
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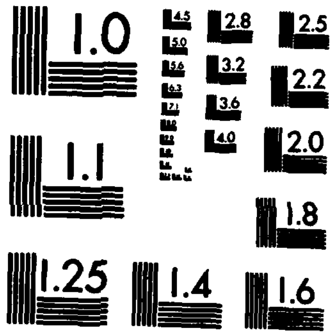
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CR 82.001

NAVAL CIVIL ENGINEERING LABORATORY
Port Hueneme, California

Sponsored by
NAVAL FACILITIES ENGINEERING COMMAND

RESOURCE RECOVERY TECHNOLOGY APPLICATION DOCUMENT

June 1982

An Investigation Conducted by
SCS ENGINEERS
4014 Long Beach Boulevard
Long Beach, California

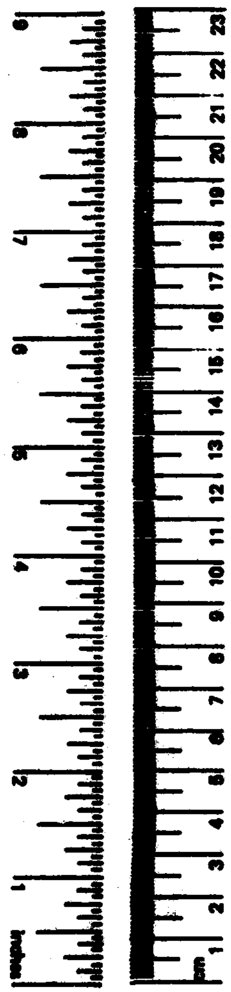
N68305-80-C-0055

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

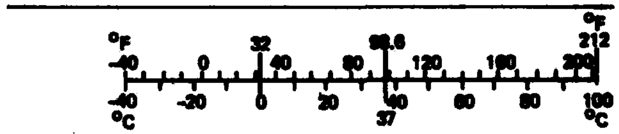
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

The technologies presented include both Navy scale (40 TPD) and municipal scale (up to 2,000 TPD) systems. The document is arranged to provide a large amount of data in a concise format and, therefore, makes liberal use of tables and charts. Systems are grouped into three categories: material recovery systems, fuel recovery systems, and combustion systems. The unit operation making up systems in each of these areas are fully described in the appendixes to the document. The document is presented in loose leaf format to allow updating as new information is developed.

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Unclassified

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Appendices | Page

SECTION I

INTRODUCTION

PURPOSE

This document is intended to assist Engineering Field Division (EFD) and Public Works (PW) personnel at Naval facilities with solid waste management programs, specifically those program elements pertaining to materials and energy recovery from solid waste. The information contained herein reflects the present state-of-the-art in solid waste resource recovery technology.

This document constitutes part of a larger Navy program to identify and develop solid waste management systems for future use. The results of the program will allow the Navy to comply with changing environmental regulations and policies, in both a cost-effective and energy-efficient manner. Most of the program effort is being devoted to field assessments of the more promising technologies, the results of which will be incorporated in subsequent updates of this document.

BACKGROUND AND SCOPE

The recovery of energy and materials from solid waste has been of interest to the Navy for many years. Numerous research programs have been conducted to develop and/or evaluate certain technologies, and most Navy facilities have formally assessed the feasibility of on-site energy recovery at some time in the last 15 years. Several facilities have implemented energy and materials recovery systems as a result.

For those facilities which chose not to implement such a program, recent dramatic changes in both environmental regulations and energy costs have renewed interest in resource recovery. The number of commercially available technologies has increased concurrently. Those EFD and PW personnel tasked with updating their original feasibility assessments are confronted with a more complicated and more important task than in years past. Current information on the technology, cost, and environmental impact of resource recovery is essential to a proper feasibility assessment.

To this end, the Naval Civil Engineering Laboratory (NCEL) Environmental Protection Division, Port Hueneme, California, contracted with SCS Engineers, Long Beach, California, in September, 1980, to prepare this document.

Its contents reflect the current state-of-the-art in materials and energy recovery, and are based on information and data from the latest published research and documented practical experience. The technologies reviewed

herein include both Navy-scale systems (10 to 40 tons per day) and municipal-scale systems (up to 2,000 tons per day) with which Navy facilities may become involved as part of a regional project.

Subsequent updates of the document will include the findings of other aspects of this overall Navy RDT&E effort. One such ongoing aspect is a legal/regulatory trend assessment. Another aspect is an assessment of future changes in Navy activities which may impact the generation (types and quantity) of solid waste. This assessment is being supplemented by waste characterization programs, a review of current Navy solid waste management practices, and the development of an energy consumption data base. When combined, the results of these program elements will permit the identification of the most appropriate technologies for Navy application. Cost and reliability data will also be obtained through special test and evaluation operating facilities and at the Navy's solid waste T&E site at NAS, Jacksonville, Florida.

Following the acquisition of needed supportive data from the larger RDT&E program, a section summarizing recommended energy and material recovery concepts will be added to this document. The recommendations will be based on systems that have been demonstrated to be both the most technically feasible and economically viable at a scale suitable for implementation at Navy shore facilities.

USE OF THIS DOCUMENT

The Resource Recovery Technology application document is designed to serve as a central source of information on generic resource recovery systems and unit operations.

This document is arranged to provide a large quantity of data in a format which enables the user to readily access the information. For this reason each system description is limited to four or less pages, making liberal use of graphs and tables where appropriate. The systems are grouped into three general categories: Material Recovery Systems, Fuel Recovery Systems, and Combustion Systems.

Material Recovery Systems (Section II) comprise those technologies where a specific component of the waste (i.e., ferrous metals, aluminum) is separated and prepared for market. Composting systems are also included as a process which produces a saleable commodity rather than a fuel or energy product. Most mechanical recovery systems for a single material cannot be justified alone, but instead depend on another system, such as refuse-derived fuel production, to prepare the material for the recovery stage. The material recovery systems described in Section II are therefore best defined as a combination of (1) the unit operation suitable for recovering a specific material, and (2) a fuel recovery or combustion system which is compatible with that unit operation. For example, a ferrous recovery system consists of a magnet integrated into a fuel recovery processing line.

Each material recovery system description concentrates on market specifications and demand, leaving the processing support systems to other chapters. Information provided for each material recovery system typically includes the following items:

- Sources of the material.
- Industrial users.
- Use specifications.
- Historical demand.
- Factors influencing demand/price.
- Costs.
- Factors favoring centralized recovery.
- Alternative approaches to recovery, including supporting unit operations.
- Complementary systems and their impact.

The actual recovery unit operations are fully described in the "Materials Handling Equipment" (MH) appendix.

Fuel Recovery Systems (Section III) are defined as those systems producing a solid, liquid, and/or gaseous fuel as their principal output. systems falling under this heading are generally the most complex, and usually involved three or more processing and handling stages. Because the product characteristics vary substantially within and between systems, the descriptions concentrate more on the technology options than on product characteristics/market specifications.

Each fuel recovery system description includes the following information:

- Fuel markets/uses.
- System applications.
- System characteristics.
- Demand considerations.
- Recovery alternatives.
- Applicable technology and unit operations (reference to appendices).
- Costs.
- Selected implementation and operating considerations.
- Complimentary systems and their impact.

Much of this information is not available for fuel recovery systems with limited operating experience. Systems falling into the latter category instead include a statement regarding their current stage of development.

Combustion Systems, Section IV includes all technologies where the resultant product is an energy product intended for immediate use. All systems reviewed produce one or more of the following energy products:

- Hot water.
- Steam.
- Hot gas.
- Electricity.

Specifications for each product and the method, equipment, and procedures necessary to produce each product are given for each combustion technology.

The typical combustion system description contains both detailed product market and technology information, as contrasted with the necessarily singular focus of the material recovery (product-oriented) and fuel recovery (technology-oriented) sections. Information presented for each combustion system includes the following:

- Product markets (characteristics and use specifications).
- Applicable technology.
- System costs.
- System efficiency.
- Complimentary systems and their impact.

Institutional considerations EFD and PW personnel are likely to encounter when planning or evaluating recovery systems are given in Section V, Institutional Considerations.

Specific considerations are briefly addressed, including:

- Planning and scheduling.
- Energy and materials markets.
- Project financing.
- Risk analysis and procurement.
- Use of outside assistance.

Additional references are provided for a more thorough discussion of each subject.

Generic unit operations summaries for most major system components appear as appendices. Information provided for each unit operation includes the following, where available:

- Types available.
- Types used commercially.
- Physical characteristics.
- General description.
- Principle of operation.
- Materials of construction.
- Advantages over other types.
- Sizing criteria.
- Accessory components.
- Support requirements (i.e., personnel training).
- Operational considerations (i.e., maintenance, controls).

- Safety and environmental considerations.
- Cost analysis.
- State-of-the-art evaluation.
- History.
- Successes.
- Failures.
- Key Problems.

Data were not available to determine all of the above information for each unit operation. Where the published information was insufficient or not available, the words "no data available" are inserted.

The equipment is divided into three general categories: Materials Handling Equipment, Air Pollution Control Equipment, and Combustion Equipment.

Items classified under materials handling include, size reduction unit operation, separation unit operations; as well as conveying, compacting, and storage operations.

Air pollution equipment includes all commonly used equipment associated with either combustion gas cleaning or process gas cleaning.

The combustion equipment section includes those unit operations or pieces of equipment directly associated with the actual combustion process. Included are waste-burning incinerators, as well as equipment to burn solid, liquid, and gaseous derived fuels.

Throughout Sections II, III, and IV references are made to selected appendices. The reference system employed is based on the three basic appendix divisions as described above. The three divisions and their reference code letters are: Materials Handling, code = MH; Air Pollution Control, code = APC; and Combustion Equipment, code = CE. Within each division, each separate unit operation appendix is identified by a single letter code. Thus, the Air Classifier appendix is coded as MH-I, corresponding to its position as the I item in the MH (materials handling) section. Unit operations with each appendix are grouped according to function (e.g., shredders and hammermills, vibrating and trommel screens, etc.). Page numbers are provided both for the entire report and for each unit operation appendix.

This cross reference system should enable the reader to quickly identify the unit operation and locate it within the appropriate appendix.

SECTION II

MATERIAL RECOVERY SYSTEMS

The general category of material recovery includes those systems which separate any saleable component from solid waste, other than a fuel or energy product. Material recovery (MR) systems range from simple source separation programs to elaborate processing systems that mechanically separate several materials from mixed solid waste. In actual practice, economical large volume material recovery occurs where a recovery component is included as part of a full recovery system, and takes advantage of the processing system already in place.

Materials for which commercial recovery is most often considered include the following (codes for subsections in this report are shown in parentheses):

- Aluminum (AL).
- Compost (CM).
- Ferrous Metal (FE).
- Glass (GL).
- Paper (PA).
- Plastics (PL).

Separate subsections for recovery of each material are presented on the following pages. The information is organized under the following headings:

- Material Markets: high concentration sources, industrial users, demand and related considerations, and standard specifications (where available).

- Alternative approaches to recovery.

- Applicable Technology: basic system(s), unit operations, and system characteristics.

- Complimentary systems and their impact.

The actual format of each material recovery subsection varies due to differences between materials and the nature of recovery. References are also made to the appendices, where the recovery equipment/unit operations are presented as a detailed supplement to the general system description.

MATERIALS MARKET

Forms found in or produced from solid waste

Activity	Material Form	Concentration in Waste
Housing, industrial, commercial, medical services, recrea-ion areas, dormitories	Aluminum cans (beverage) light and rigid foils such as frozen dinner trays, packaging, furniture.	Aluminum is approximately one percent of post consumer food waste stream. Data for Navy facilities are not available.

Industrial Users

Name	Specific Process	Material Form Required
Scrap dealers	Once scrap identified as aluminum, it is cleaned, dried, shredded, crushed, screened, separated from other scrap (magnetic) and then baled or brignetted for shipment.	All aluminum cans, frozen food trays, foil, lawn furniture (with webbing removed) and aluminum no greater than 1/16 in in thickness and 1 ft square.
Secondary smelters	Charging scrap into a reverbatory furnace, sampling molten metal to determine its composition, introducing any necessary additional compounds and aluminum to bring the melt to specification	Same as above.
Non-integrated foundries and fabrications	Die casting; permanent mold casting, and sand casting	Same as above.
Primary producers	Recycled into can stock	Same as above.

Form	End Use	Specifications
Density - is not specified and shall be agreed upon between the purchaser and the seller. Fines - Shall contain not more than the amount of miners 12 Mesh (U.S. Standard Sieve) material, described in following action: Class A material shall contain not more than 1% by weight of fines. Class B material shall contain not more than 3% by weight of fines.	Secondary aluminum smelters Primary aluminum producers Aluminum scrap dealers, Iron and Steel Industry Foundries, Non-integrated aluminum producers, Independent aluminum fabricators	ASTM E753-80

Factors Favoring Centralized Recovery

- Effective mechanical/electromagnetic separation in concert with front-end processing is many times more efficient than manual separation.

- Market specifications can be met by state-of-the-art separation equipment.

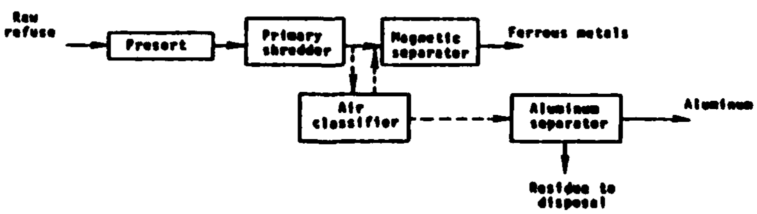
Factors Favoring Source Separation

- Cleaner product.
- Lower capital investment.
- Flexible in case of container legislation or other interuption of flow.

Alternative Approaches

System	Description
Separate vehicle for collection	Residents/workers separate metals from waste stream prior to placing waste in collection containers. A vehicle allocated expressly for collection of sorted metals then collects the metal. (Typical vehicles - pick-up truck, trailer, refuse collection vehicle which is no longer in use, other vehicles.)
Refuse vehicle collection	Separated metals are collected in a separate compartment of the normal refuse collection vehicle.
Materials recovery facility	Solid waste is shredded and classified. Process heavies are separated from ferrous, and aluminum is uncovered using eddy current separator.

APPLICABLE TECHNOLOGY



Unit Operations

Number	Function	Commonly Used Equipment	Reference No.
1	Gross sorting of materials, removal of hazardous, bulky, or oversized items	Handsorting, front-end loader	Not included
2	Size reduction of refuse to more uniform pieces, liberate composite materials	Hammermills, shredders	MH-E, MH-F

3	Separate refuse into two concentrate streams	Air classifier, trommel screens	MH-I, MH-D
4	Separate ferrous metals from refuse stream	Magnetic drum separator, belt magnet separator (overhead)	MH-J, MH-K
5	Separate aluminum from air classifier heavies	Dense media separator, Eddy current separator	MH-L, MH-M

System Characteristics

- Requires iron-free feed from air classifier.
- Eddy current separator most common unit in use for aluminum.

COMPLIMENTARY SYSTEMS AND THEIR IMPACT

- Source separation and aluminum separation technology are not compatible.
- Air knife or additional classification step can help clean aluminum fraction.
- Trommel screen will provide system with whole-can feed, which can be separated efficiently by eddy current device.

MATERIAL MARKETS/USES

The primary use of composted solid waste has been its application to land as a soil amendment to increase crop production; limit erosion rates or other improvements in soil characteristics. Other uses such as animal feed, or fuel have been suggested but have not been demonstrated. Most solid waste derived composts do not contain adequate amounts of nitrogen or phosphates to be strictly classified as a fertilizer, hence the use as an amendment.

Compost is supplied loose, bagged, or it can be pelletized for ease of transport and distribution, or slurried for ease of application.

Use Specifications

Exact specifications for compost have not been established. Experience has shown that carbon to nitrogen ratios of below 20 are preferred to ratios above 20. Other critical factors for crop use include: soluble salt levels (should be low), potassium and phosphorus levels (desired levels vary with use), and heavy metal content (particularly important if consumption crops are being produced).

Type of compost, type of soil, climate and specific use all effect the potential useage of compost.

Historical Demand

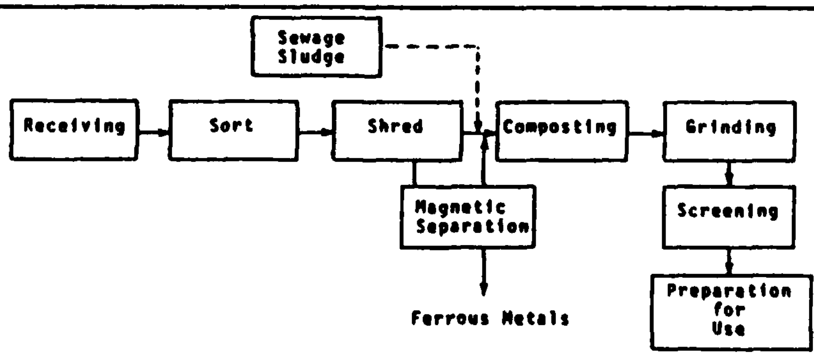
Composted refuse has been proved technically feasible for many years, particularly in Europe. The lack of successful U.S. based composting operations is primarily a result of limited markets for the compost. When the compost could not be sold and plants continued producing, large stockpiles were created. The stockpiles had to be disposed at an unanticipated cost to the operator.

There is currently no established market for composted refuse. Land reclamation or crop production acres must be identified and secured by the compost producer.

Factors which influence price:

- Proximity to market.
- Absence of competitive products.
- Governmental cooperation.
- Guaranteed product quality.
- Demonstrated success.
- Availability of land needing reclamation.

APPLICABLE TECHNOLOGY



Unit Operations

Operation	Function	Commonly Used Equipment	Reference No.
Receiving	Collect refuse	Tipping floor, pit	Not included
Sort	Remove uncompostable items	Manual labor	N/A
Shred	Size reduction, mixing	Shredders	MH-E, MH-I, MH-L
Magnetic separator	Remove ferrous	Drum or belt separators	MH-F, MH-G
Composting	Digestion of refuse	Windrows, tanks, bins	Not included, CE-B
Grinding	Size reduction, mixing	Shredders	MH-H, MH-K
Preparation for use	Final preparation bagging	Bagging machines dryers	Not included

System Characteristics

Composting is the aerobic decompostion of organic materials. The processing steps illustrated above are intended to enhance the decomposition process. Composting systems can be divided into two basic types: mechanical high-rate digestion, and open-windrow methods. In high-rate digestion the decomposition is performed in specifically designed structures using controlled temperatures and air flow rates. Manufacturers have claimed composting times of as little as a few hours. The efficiency of such short time digestion is questioned. The destruction of pathogenic organisms, such as occurs in windrow-type composting, is also questioned.

Open windrow-type composting is typically accomplished by spreading the prepared refuse out on the ground in mounds or in trenches (windrows). The windrows can vary in dimensions, dependent on the equipment used, the amount of refuse to be processed, and the land area available.

Other digestion alternatives have been successfully employed. Some systems combine windrowing with forced air circulation by placing the windrows inside a environmentally controlled building. Still other systems use rotating cylinders to constantly mix the prepared refuse thus promoting more complete and rapid destruction.

Limitations

Composting has the potential to reduce the quantity of solid waste for landfilling. Existing systems have experienced a 60-70 percent volume reduction and a 20-30 percent reduction in weight.

Removal of glass, plastics, and non-ferrous metals presents problems for composting operations. No mechanical means have been developed which remove these materials with high efficiency.

Composting refuse can be maloderous if not properly managed. Flies and rodents can also become problems in a composting plant. Proper housekeeping and operation can reduce these problems.

MATERIAL MARKETS

Forms Found In or Produced From Military Solid Waste

Activity	Weight Per Cent (Note 1)	Weight Per Cent Material Form	(Note 2)
Laundry	3	Tin cans	61.0
Exchanges, commissaries	2	Bimetal tin cans	11.1
Ordinance	<1	Bimetal tin-free cans	3.3
Offices, training	5	Bottle caps-paper with metal ends	3.9
Food service	5		
Shops, berthing piers	7	Misc. iron, other	20.7
Warehouses	3		
Housing	6		

Notes: 1) Figures listed are for total metals; ferrous fraction is typically 90% of total metal portion, SCS Engineers, 1972
2) Ferrous fraction only; from DeCesare, R.S.

Industrial Users

Name	Specific Process	Material Form Required
Copper Industry	Precipitation	Loose, shredded as agreed upon between purchaser and supplier. Bulk density: 30 (lb/cu-ft)
Iron and Steel Foundaries	Continuous or ingot casting, rolling, and shaping	Loose, balled, or baled (industry practice is to specify a maximum bale size that may vary among users) as agreed upon between purchasers and suppliers Bulk density: 50 (lb/cu-ft)
Iron and Steel Production	Furnaces - blast, open hearth basic oxygen, electric arc, cupola	Loose or baled as agreed upon between purchaser and supplier Bulk density: 75 (lb/cu-ft)
Detinning Industry	Detinning	Shredded, 95 weight % shall be -6, +1/2 in. (-152, +12.5mm); shall not be baled, burned, incinerated, or pyrolyzed Bulk density: 25 (lb/cu-ft)
Ferroalloy	Blast furnace	Loose as agreed upon between purchaser and supplier Bulk density: 50 (lb/cu-ft)

Use Specifications

Element	Copper Industry (Precipitation Process)	Iron and Steel Foundries	Iron and Steel Production[A]	Detinning Industry[B]	Ferroalloy Production
Phosphorus, max		0.03	0.03		0.03
Sulfur, max		0.04	0.04		
Nickel, max		0.12	0.8		
Chromium, max		0.15	0.10		0.15

Molybdenum, max		0.04	0.025		
Copper, max		0.20	0.10		0.20
Aluminum, max		0.50	0.50	4.00[E]	0.15
Tin		0.30 max[D]	0.30 max	0.15 min[F]	0.30
Lead, max		0.03	0.15		
Zinc, max		0.06	0.06		
Iron (metallic, min	96.0				
Silicon, max			0.10		
Manganese, max					0.35
Carbon, max					0.6
Titanium, max					0.025
Total combustibles, max	0.2[C]	4.0	4.0		0.5[G]
Metallic yield, min		90.0	90.0		90.0

[A] Experience has shown that material which has been incinerated probably will not meet these requirements.

[B] A minimum of 95 weight % of the material delivered shall be magnetic. Nonmagnetic material attached to the original magnetic article may be included in the minimum requirement.

[C] The scrap shall be appropriately processed (for example, by burning, chemical detinning, etc.) to be virtually free of combustibles.

[D] For steel castings, the requirement for tin content is 0.10 max %.

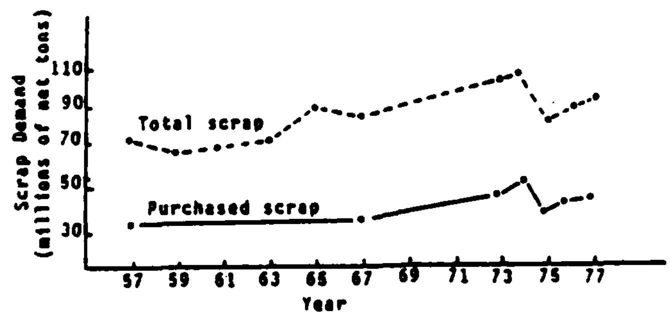
[E] Not based on melt analyses due to aluminum losses during melting; to be determined by a method mutually agreed upon between the purchaser and supplier.

[F] Refer to sections on magnetic fraction and chemical analysis of tin in Methods E 701. Normal separation of white goods and heavy iron yields tin contents equal to or greater than 0.15 weight %. Lesser tin contents would impact severely the value of the scrap to detinners.

[G] The scrap shall be appropriately processed (for example, by burning, chemical detinning, etc.) to be virtually free of combustibles.

Source: American Society for Testing and Materials
Designation: E 702-79

Historical Demand



Factors which influence price

- Availability of scrap.
- Length of contract for supply of recovered metals.
- Level of contaminants (% of total weight).
- Cost of removing contaminants.
- General level of the demand for steel.
- Cost of processing scrap into product compared to cost of processing raw materials.

Comments on future market demand

- May increase if freight rates and tax policies become more favorable for recovered metals.
- May increase if companies are willing to enter into long-term contracts for scrap.
- Ability to remove contaminants improves.
- Supply of raw materials diminishes or prices escalate rapidly.
- Furnaces technology is developed to accept larger scrap portions.
- An expanded scrap market must develop to handle expected increases in scrap from resource recovery plants.

Factors favoring centralized recovery

- Shredding metal may be more economical at a centralized facility.
- Willing market.
- Efficient for large amounts of waste.
- Source for salvage market is centralized.
- No public participation necessary.
- Handles waste from any facility.

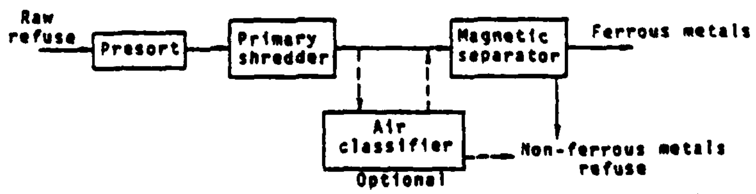
Source separation

- Willing market.
- Flexibility in adjusting to different flows of wastes.
- Contamination levels are likely to be low.
- Shredded product would be cleaner if presorted.
- Initial capital and operating costs are low.

ALTERNATIVE APPROACHES

Source separation	Description
Separate vehicles for collection.	Residents/workers separate metals from waste stream prior to placing waste in collection containers. A vehicle allocated expressly for collection of sorted metals then co lects the metal. (Typical vehicles - pick-up truck, trailer, refuse collection vehicle which is no longer in use, other vehicles.)
Refuse Vehicle Collection	Separated metals are collected in a separate compartment of the normal refuse collection vehicle.
Materials Recovery Facility	Handles unprocessed wastes. A magnetic separator would be the key component. See applicable technology section.

APPLICABLE TECHNOLOGY



Unit Operations

Number	Function	Commonly Used Equipment	Reference No
1	Gross sorting of materials, removal of hazardous, bulky, or oversized items	Handsorting, front-end loader	Not included
2	Size reduction of refuse to more uniform pieces, liberate composite materials	Hammermills, shredders	MH-E, MH-F
3	Separate refuse into two concentrate streams	Air classifier, trommel screens	MH-I, MH-D
4	Separate ferrous metals from refuse stream	Magnetic drum separator, belt magnet separator (overhead)	MH-J, MH-K

System Characteristics

- Separates ferrous metals from waste stream to produce a clean marketable product.
- Magnetic drum is scalping device and will not pick up small magnetic particles beneath conveyed waste.
- Drawback to belt separators - magnetics are abrasive and result in accelerated belt wear.

COMPLEMENTARY SYSTEMS AND THEIR IMPACT

- Additional air classifiers to remove more of the light fraction.
- Ferrous metals concentrate to clean and separate ferrous metals into two fractions - cans and other light gauge metals and castings, forgings, and rolled stock.
- Can compactor to increase density of the light ferrous metals product.
- Balers to bundle material into uniform sizes.

MATERIAL RECOVERY	Glass	MR-GL	P. 1 of 4

MATERIAL MARKETS

Forms found or produced from Military Solid Waste

Activity	Material Form	Concentration in Waste
Food Service, Housing	Bottles, Jars	5-10 percent by weight, including flint (clear), amber, and green glass colors.

Industrial Users

Name	Specific Process	Material Form Required
Glass Container manufacturers (Large Volume)	Sort, Magnetic separation, washing, crushing, screening	Whole or broken glass ("cullet"); relatively low contamination.
Glass bottle users	Sort, wash	Whole bottles (wine, beverage).
Intermediate glass Processing (small volume)	Magnetic separation, color sort (manual), separate crushing	Whole bottles; mixed bottles and cans.

Specifications

Form	End Use	Specification
Whole bottles or mixed material	Refining	Whole, relatively clear but mixing metal cans is acceptable.
Cullet source separated, or otherwise hand sorted.	Glass container manufacture (per GCMI)	• <0.5% H_2O • 100% <50mm, 5% <11mm • <0.2% organics • <0.5% magnetics; <6mm • <1.0% inorganics; <6mm
	• Flint	• 95-100% flint • <5% amber • <1% green
	• Amber	• 90-100% amber • <10% flint • <10% green
	• Green	• 50-100% green • <35% amber • <15% flint
Cullet (froth flotation product)	Glass container manufacture (per GCMI)	Same as sorted product, except: • <0.14% magnetic metals.

Historical Demand

Glass has commonly been recycled for many years, and the technology for reuse in commercial process is well developed. Most glass produces already use 10 to 15 percent glass cullet in their furnace feed, with some using as much as 50 percent (in-plant cullet waste).

Post-consumer glass of good quality is welcomed in the industry as an energy saving step. Most glass recycling includes an Intermediate Glass Processor (IGP), who sorts the glass and processes it for delivery to the plant. IGP's are the logical broker for a large-volume resource recovery program, as they are familiar with the quality of most post-consumer products, can except a larger volume of material, and will generally pay a higher price as the only "middleman". The glass container industry as a whole has actively promoted it's interest in post-consumer glass by developing and publicizing standard specifications (listed above).

Factors which influence price

- Energy prices
- Contamination
  - color
  - ceramics
  - metals, other inorganics.
- Transportation.
- Beverage container legislation.
- Whether sale is to recycling center, IGP, or direct to manufacturer/user.

Comments on Future Market Demand

- Glass container industry should continue to promote use of post-consumer glass.
- Several major plants are planned almost exclusively for recycled glass, and recycling bills in several states will provide the necessary capacity demand for expansion of the market.

RECOVERY ALTERNATIVES:

Recycling/Buy Back Center

- Closer control of product quality, but limited to small volume operations.

Mechanical Separator

- Both optical sorting and froth floatation are potentially less expensive per ton than manual separation. Poor reliability and product quality have been the two greatest drawbacks to date. Continued research and experience could result in more extensive commercial acceptance. Even then, the economics of mechanical glass recovery will be poor for Navy scale waste flow.

Source Separation

- Similar to buy-back centers, except curbside collection more conducive to medium scale recovery. Source separation could conceivably serve any size of facility but must include materials other than glass if system is to pay for itself.

ALTERNATIVE APPROACHES

Centralized Recovery

- Buy-back center on base, which pays for clear recycled glass (whole and/or broken) on a per pound basis (based on the prevailing price/transportation costs.

Separate Collection

- Glass is collected both at residences (curbside) and at major generation point (mess, supply) in a separate truck. Glass is then brought to central storage area and dumped, either in a tipping area or into a buyer-supplied bin. It is then loaded and handed to the buyer for processing. In order to be economical, the system should; (a) include other separted materials; and (b) be justified based on an F.O.B. facility price.
- Glass is collected mixea with cans and newsprint. Material is hauled to buyer, or separted by hand at Navy facility. Separated, material is then hauled to the respective markets. On-base separation is not normally economical, and intermediate glass processors are not too common. The viability of this approach therefore depends on location.

APPLICABLE TECHNOLOGY

- For source separation, a variety of compartmentalized trucks/trailers are available.
- Buy-back/recycling center designs can vary widely, and typically consist of no more than a concrete slab and some retaining walls to serve as bins. Some buyer-supplied bins may also be used.

System Characteristics (Source Separation/Recycling)

- Labor intensive.
- Low capital cost, typically limited to construction of recycling center and purchase of truck and/or trailers.
- 20-50 percent recovery for curbside system, lower for buy-back system or volunteers recycling center.
- Strong markets throughout U.S.
- Personnel sorting or handling glass should be required to wear protective clothing identical to solid waste handlers.

COMPLIMENTARY SYSTEMS

- Common collection of cans and paper.
- Recycling center designed to accept other materials.

MATERIAL MARKETS

Forms found or produced in Military Solid Waste

Activity	Material Form	Concentration in Waste
All	• Newsprint	5-10%
	• Corrugated	0-20%
	• White Ledger	0-10%
	• Computer Printout (CPO)	0-50%
	• Tab Cards	0-10%

Industrial Users

Name	Specific Process	Material Form Required
Paper Mills	Pulping and reprocessing	Newprint Corrugated White Ledger CPO Tab Cards Kraft Paper (Combination of above)
Insulation Manufacturer	Grinding and fireproof coating	Newspaper

Specifications

Form	End Use	Specification
Newsprint	Pulping	• Usually Baled is preferred; contamination should be <10%, particularly free of coated (magazines) or long fiber papers.
	Boxboard, Insulation	Unknown
White Ledger, CPO	Pulping	• Baled or stacked; any level of contamination should be avoided, as most buyers will not specify a contamination limit.
Corrugated	Pulping	• Baled.
Tab Cards	Pulping	• Boxed or Baled.

Historical Demand

Paper recovery has been practiced for many years, but only within the past decade has the market expanded to accept post-consumer paper. Prior to 1970, paper recycling concentrated on industrial scrap and other inherently pure waste streams. Since that time, the market has expanded due to; (a) increased exports; (b) increased industry acceptance of recycled paper; and (c) expansion of the industry's capacity to accept recycled paper due to growth in the volume of recycled paper available.

The paper market is quite volatile; newspaper prices, for example, have varied from as low as \$5/ton to as high as \$70/ton in some locations; all over a period of 6 to 7 years. Price stability is guaranteed by many buyers through "floor prices", regardless of how the market performs.

Factors Which Influence Price

- Contamination (although contamination more often results in rejection of a load rather than price reduction).
- Transportaion costs.
- Market conditions
  - export level
  - competition from other (sporadic) markets, such as insulation
  - availability of recycled paper from other major sources

Comment on Future Market Demand

- Expansion of markets for all recycled paper as supply expands.
- Several companies are rapidly expanding their capacity, with mills devoted to recycled paper.

RECOVERY ALTERNATIVES

- Source Separation via Separate Collection (Residential Newsprint).
- Source Separation of pure streams at Source (office paper, corrugated, CPO, tab cards).
- Hand sorting of paper from mixed trash (newsprint, corrugated).

ALTERNATIVE APPROACHES

- Source Separation via Separate Collection Newsprint is collected from homes in bundles or bags; using either separate vehicles (see MRS-GLS) or compartments/racks built onto the regular collection vehicles. The paper is off loaded at the storage yard and sorted to remove bags and other contaminants. Paper is then stored loose or stacked, and shipped when a full load is justified.

- Source Separation of pure waste streams at the source.

  High grade office paper (white ledger, CPO) is separated at the point of generation rather then mixed with regular refuse. The paper is stored flat in a desk top container or separate trash can. Custodians collect the paper each evening and take it to collection/storage area (bin) in each building or complex. The bins are later transferred to central depository on base, for either loose storage or baling. Under a full service contract, the buyer will pick-up the paper on call, with other cost of transport factored into the contract price. Otherwise, Navy personnel transport it to market.

  Corrugated and tab cards are handled in much the same manner, except that storage, boxing, and/or baling typically takes place at the point of generation.

- Hand sorting of paper from mixed trash.

  Separated mixed material is collected at curbside and transported to a central location for sorting. Once the cans and glass are removed, the newsprint is baled or stored loose. Poor quality is common, as removing wet garbage from the glass and cans will contaminate paper. The material is often accepted, but at a lower price than pre-sorted newprint.

APPLICABLE TECHNOLOGY

	References
• Truck newspaper racks.	Not included
• Compartmentalized vehicles or trailers.	Not included
• Balers.	MH-H
• Sorting conveyors.	MH-B
• Bins.	Not included

System Characteristics

- Labor intensive.
- Market is typically strong, but marked geographic distribution of demand will influence economic feasibility.
- Both curbside newsprint collection and desktop separation of high grade paper are proven systems; common sense usually dictates the most efficient approach at a given base or building.
- High degree of recovery is possible for white ledger, CPO, tab cards, and corrugated. Newsprint recovery is usually the most successful of curbside components, and may range from 20-75 percent. Strong market contracts are a must, due to market volatility and storage space required.

COMPLIMENTARY SYSTEMS

- Curbside collection of glass and/or metal cans, whether mixed or separated.
- Recycling/buy-back centers for other materials.
- Energy recovery from mixed solid wastes.

MATERIAL MARKETS

Forms Found or Produced from Military Solid Waste

Activity	Material Form	Concentration in Waste*
Food Service, housing, recreation areas, medical, ships, storage area	Bottles (largest percentage by volume), packaging, foam trays, bags, cups, and other discarded consumer goods	Thermoplastics - 89% high and low densty polyethylenes, polypropylene, polystryene, PVC (polyvinyl chloride), thermosets Plastics - 2%

Industrial Users

Name	Specific Process	Material Form Required
P.E.T. bottle recyclers (Polyethylene terephthalate polyester bottles)	Separating, cleaning, washing and grinding Production to key components, then repolymerized into fiber grade P.E.T. polyester	Crushed, baled, ground; clear and green, mixed

Specifications

Form	End Use	Specification
Ground or baled; if ground P.E.T./packaging may be preferred (material has gone through 1/2" screen and is contained in box weighing 600-1,000 lbs)	Polyester products (non-food contact)	2 liter bottles only; loose, baled (not collapsed), clean (emptied of liquid, usually soda pop), no cap or loose cap

Historical Demand

P.E.T. bottles are the only post-consumer plastics recycled at this time. The number of P.E.T. beverage bottles being produced is steadily increasing.

* Note -

- Thermoplastics can be melted and reformed numerous times.
- P.E.T. Bottles (polyethylene terephthalate) are the only consumer plastics being recycled in any appreciable quantity.
- Thermosets can not be melted and reformed.

Factors which influence price

- Amount of contaminants.
- Availability of P.E.T. bottles.
- Transportation costs
  - recycler picks up bottles
  - bottles shipped to recycler
  - location of recycling plants.
- Whether deposit law for P.E.T. bottles is in effect.
- Price of virgin resin.

Comments on future market demand

- Expanded use of recycled P.E.T. for unsaturated polyester resins for non-food contact containers and other applications.
- May become more desireable as a fuel supplement in RDF systems. The fuel value of P.E.T. is 10,000 Btu/lb.
- Expanded use of P.E.T. bottles in container field.

RECOVERY ALTERNATIVES

Centralized Recovery

- Recycling center for P.E.T. bottles and other recycled materials.
- If volume high enough, P.E.T. bottles can be separated by machinery rather than by hand.

Source Separation

- Cleaner scrap (caps loose or removed before shipping).
- Reduces volume of material going to landfill.
- Does not rely on large volume to operate.

Material collected at collection points. Brought to central point where P.E.T. bottles are sorted by hand. Bottles are stored in bins until quantity reached is economically feasible to transport to bottle manufacturers, off-base recycling center, or directly to the recycler. At this central place, the base may operate a baler or grinder.

Base personnel are informed of source separation and know it is to be accomplished. Bottles are put in an appropriate container for collection on same day as other refuse or on alternate days. Bottles are taken to central locations to be containerized for shipping. At this central place, the base may operate a baler or grinder, depending on the specifications of the recycler.

System Characteristics

- Labor intensive.
- Does not require large capital outlay even if a baler or grinder has to be purchased.
- 100% recovery P.E.T. bottles.
- System would retrieve 2 liter and 1 liter soda bottles.
- Ready market for recycled bottles.
- P.E.T. bottles would be set aside by base personnel at each collection point or waste is taken to central place where bottles can be separated by hand.
- As more P.E.T. bottles of different sizes appear in the waste stream, no difficulty in sorting new bottles should occur.
- Personnel sorting bottles should be required to wear protective clothing identical to solid waste handlers.

COMPLEMENTARY SYSTEMS

- Slow moving conveyor system to pick bottles from waste stream.
- Storage bin system.
- If source separation system, separate or piggy-back system for collection of P.E.T. bottles from collection points.

SECTION III

FUEL RECOVERY SYSTEMS

Fuel recovery (FR) systems process and segregate a portion of mixed solid waste for use as a fuel. Most fuel products are intended as partial substitutes for conventional fossil fuels, and take the form of that fuel (i.e., solid, liquid, or gas) for ease of handling and combustion.

It is difficult to categorize fuel recovery systems into a small number of distinct groups, particularly by fuel form alone. To produce each fuel form, there are often several commercial-scale processing systems available. Slight variations within system categories and solid waste composition also produce variations in fuel composition. For simplicity, the following generic system categories are presented in this section (system codes are shown in parentheses):

- Solid fuel (SF)
  - Raw MSW (RW)
  - Chemically powdered RDF (CP)
  - Coarse fluff RDF (CF)
  - Densified RDF (DN)
  - Physically powdered RDF (PP).
- Gaseous fuel (GF)
  - Low-Btu gas (pyrolysis) (LB)
  - Medium-Btu gas (pyrolysis) (MBP)
  - Medium-Btu gas (anaerobic digestion) (MBA)
  - High-Btu gas (anaerobic digestion) (HB).
- Liquid fuel (LF)
  - Pyrolysis oil (PO)
  - Gasoline (GS).

The format of all subsections is similar, emphasizing the technological variations rather than the site-specific marketing considerations (note the contrast with Section II).

Each subsection contains information under the following major headings:

- Fuel Characteristics: general information, recommended applications, system and output specifications, and demand restrictions.

- Recovery Alternative: comments on Navy applicability, and alternatives to central processing.
- Applicable Technology: generic system description, unit operations, operating experience, and cost.
- Complimentary systems and their impact.

Much of the discussion is general in nature, as specific descriptions might tend to favor one system variation over another. Extensive reference to the appendices is used for additional detail.

Typical fuel characteristics for liquid and gaseous fuel products are presented in the appropriate subsections. Solid fuel characteristics are presented below for ease of comparison.

	PROCESSING ALTERNATIVE					
Characteristic	Raw MSW	Coarse Fluff RDF	Fine Fluff RDF	Densified RDF	Physically Powdered RDF	Chemically Powdered RDF
Heating valve (Btu/lb)	4,000-6,000	6,000-7,000	6,000-7,000	6,000-7,000	7,500-8,500	7,500-8.500
Moisture 20-40 content (%)	20-35	20-35	20-35	0-10	0-10	
Ash content (%)	20-30	15-25	15-25	15-25	15-25	15-25
Total volatile (%)	40-60	65-80	65-80	65-80	65-80	65-80
Fixed carbon (%)	4-8	5-9	5-9	5-9	5-9	5-9
Carbon (%)	25-35	30-40	30-40	30-40	30-40	30-40
Hydrogen (%)	3-6	3-6	3-6	3-6	3-6	3-6
Nitrogen (%)	0.5-1.0	0.5-1.0	0.5-1.0	0.5-1.0	0.5-1.0	0.5-1.0
Sulfur (%)	0.1-0.5	0.1-0.5	0.1-0.5	0.1-0.5	0.1-0.5	0.1-0.5
Chlorine (%)	0.4-0.7	0.4-0.7	0.4-0.7	0.4-0.7	0.4-0.7	0.4-0.7
Bulk density (lb/ft)	2-4	3-5	3-5	30-35	25-30	25-30
Particle size distribution, largest (in)	10-15*	4-7	2-3	2-4	100 mesh	150 mesh

* Excludes oversize and bulky items.

FUEL RECOVERY	Raw (unprocessed) Solid Waste	FR-SF-RW	P. 1 of 2

FUEL MARKETS/USES

Fuel Characteristics

Unprocessed solid waste has only limited value as a saleable fuel. Only combustion systems designed specifically for solid waste are suitable.

Potential Uses	System Type	Restriction/Limitations
Combustion	Modular incineration	Raw MSW fuel
	Water wall incineration	Combination with municipal partner necessary due to size constraints.
Refinement	RDF production	Market for fuel

System Specifications

System Characteristic	Specification	Typical Range	Important to:
Capacity	Tons/hour	7 - 125	Handle expected waste flow
Capital cost	Dollars/ton	1,000-10,000	Evaluate cost effectiveness
Facility size	Area	1 acre-10 acres	Fit into available space

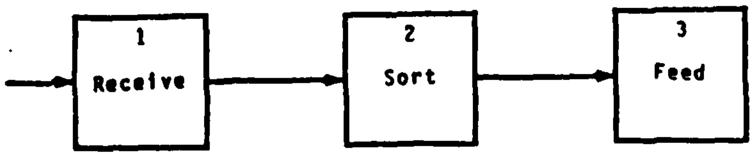
Demand

Price is a function of:

- Displaced fuel cost and availability.
- RDF quality, quantity, and deliverability (guaranteed/non-guaranteed).
- Future conventional and alternate fuel price trends.
- Technical compatibility of combustion equipment.
- Air pollution control requirements.
- Residue disposal requirements.

There is virtually no demand for raw solid waste among industrial or military coal users.

APPLICABLE TECHNOLOGY



FUEL RECOVERY	Raw (unprocessed) Solid Waste	FR-SF-RW	P. 2 of 2

Unit Operations

Number	Function	Commonly Used Equipment	Purpose
1	Receive	Concrete tipping floor Concrete pit	Organize and store incoming refuse
2	Sort	Clamshell crane Front-end loader	Remove oversize and bulky items
3	Feed	Clamshell crane Front-end loader	Control material throughput

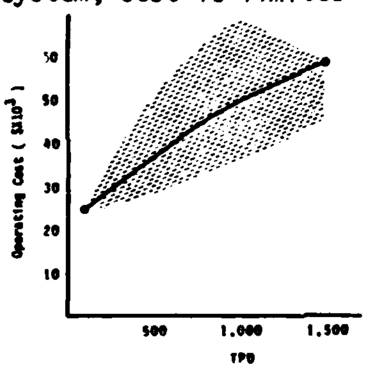
Personnel Requirements: 0-100 tpd, 1-2 operators.

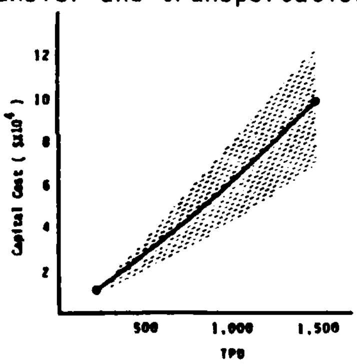
Marketability of product: 0-150 tpd, modular incineration only.
150-250 tpd, modular or field erected incinerator.
250-2,000 tpd, field erected incinerator only.

Operating example: Numerous heat recovery incinerators on line

Applicability: Military only - modular incineration
regional - modular incineration or field erected incinerator.

Cost: Excluding combustion system, cost is limited to transfer and transportation.





COMPLIMENTARY SYSTEMS

Source separation

- Removal of aluminum cans, tin-coated steel cans, glass containers, and any other non-combustible material will improve waste fuel characteristics.

- Removal of office paper, newspaper, corrugated cardboard, or any other combustible material will degrade waste fuel characteristics.

Selective waste acceptance

- Waste of commercial origin has more desireable fuel characteristics than waste of residential origin.

FUEL RECOVERY	Chemically Powdered RDF	FR-SF-CP	P. 1 of 3

FUEL MARKETS/USES

Fuel Characteristics

Chemically powdered RDF is the most refined form of solid RDF available. The principal difference between physical and chemical powdering is the addition of an embrittling agent to the latter, improving the final stage of production. Use restrictions and advantages are similar to those of physically powdered RDF (FR-SF-PP).

Potential Uses	System Type	Restriction/Limitations
Combustion	Suspension-fired coal boiler or heater	RDF blended with pulverized coal

System Specifications

System Characteristic	Specification	Typical Range	Important to:
Capacity	Tons/hour	Data are not available to determine typical ranges	Handle expected waste flow
Capital cost	$/ton		Evaluate cost effectiveness
Facility size	Area		Fit into available space
Particulate emissions	gr/dSCF		Obtain air pollution operating permits
Product output			Evaluate operating economies
RDF	Ton RDF/ton MSW		
Ferrous scrap	Ton scrap/ton MSW		
Other			
Power Consumption	KWH/ton		Compatible with existing system

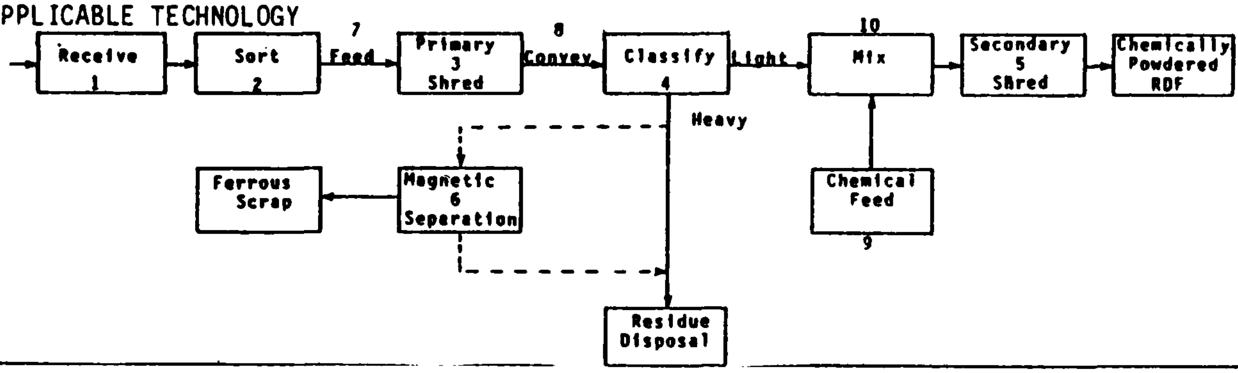
Demand

Price is a function of the same variables as physically powered RDF. The cost may be slightly higher due to chemical additives, which could be offset by reduced operating and maintenance cost for final grinding stage.

RECOVERY ALTERNATIVES

Same as for physically powdered RDF (FR-SF-PP).

APPLICABLE TECHNOLOGY



Unit Operations

Number	Function	Commonly Used Equipment (Reference)	Purpose
1	Receive	Concrete tipping floor Concrete pit (not included)	Organize and store incoming refuse
2	Sort	Clamshell crane, front-end loader (not included)	Protect equipment from unprocessibles
3	Primary shred	Horizontal/vertical hammermill (MH-E, MH-F)	Size reduction - homogenization
4	Classify	Vertical/rotary air classifier, ballistic classifier, trommel screen (MH-I, MH-D)	Separation of organics/inorganics
5	Secondary shred	Horizontal/vertical hammermill	Size reduction
6	Magnetic separation	Overhead, electromagnetic, belt magnetic separator (MH-J, MH-K)	Separation of ferrous scrap/inorganics
7	Shredder feed	Primary conveyor (MH-B)	Conveyance/control raw waste feed
8	Materials conveyance	Secondary conveyor (MH-B)	Transport of waste from operation to operation
9	Chemical feed	Spray chamber (Not included)	Meter embrittling agent to waste
10	Mixing chamber	Rotary drum, agitation arms agent into intimate contact with waste (Not included)	Bring embrittling

Personnel Requirements

- 0-250 tpd, one operator, two assistants, one mechanic.
- 250-750 tpd, one operator, three assistants, one mechanic.

Marketability of Product

- Same as for FR-SF-PP.

Operating Example

- No operating systems.

Applicability

- Military only - not feasible in 0-40 tpd range
  Regional - minimum of 200-250 tpd for economic feasibility.

Cost

- No data available for commercial systems.

COMPLEMENTARY SYSTEMS AND THEIR IMPACT

Source Separation

- Removal of aluminum cans, tin-coated steel cans, glass containers will enhance fuel processing characteristics.
- Removal of office paper, newspaper, corrugated cardboard will enhance fuel processing operations but degrade fuel heat content and reduce fuel quantity.
- Removal of tin-coated steel cans will reduce ferrous scrap recovered.

FUEL MARKETS/USES

Fuel Characteristics

Coarse fluff RDF represents the least refined form of processed solid waste commercially used as a solid fuel substitute. The principal difference between coarse fluff and other RDF forms is the degree of processing applied. The resulting product typically has a larger size distribution (4 to 7 in nominal) and may contain a higher percentage of inorganic matter due to limited classification (air, screens).

The principal users of coarse fluff RDF are limited to grate fired incinerators and boilers. Industry concerns over boiler slagging and corrosion from entrained inorganics has limited the market growth of coarse fluff RDF.

Potential Uses	System Type	Restriction/Limitations
Combustion	Modular incineration	Alone or mixed with raw MSW.
	Solid fuel (boiler)	Alone or mixed with original fuel.
	Solid fuel (heater)	Alone or mixed with original fuel.
	Solid fuel (boiler/heater)	Unless equipped with automatic ash handling, technical feasibility is doubtful.

System Specifications

System Characteristic	Typical Specification	Range	Important to:
Capacity	Ton/hr	60-150	Handle expected waste flow.
Capital cost	Dollars/ton/day	$6,000-20,000	Evaluate cost effectiveness.
Facility size	Height (ft) x length (ft) x width (ft)	1 acre - 25 acres	Fit into available space.
Product output			
RDF	Ton RDF/ton MSW	.75-.85	Evaluate operating economies.
Ferrous scrap	Ton scrap/ton MSW	.03-.06	
Power consumption	KWH/ton	29-50	Compatible with existing distribution system.

Demand

Price is a function of:

- Displaced fuel cost and availability.
- RDF quality, quantity, and deliverability (guaranteed/non-guaranteed).
- Future conventional and alternate fuel price trends.
- Air pollution control requirements.
- Residue disposal requirements.

Demand is most often controlled by the questionable combustion characteristics and compatability of the fuel with most coal-fired combustion systems. Significant improvements in the fuel characteristics (particularly inorganic content) can be made by retrofitting a trommel screen ahead of the first shredder. Other improvements involve a substantial modification of system and equipment design, and are too costly to retrofit. Based on current knowledge, a fine fluff RDF system is usually preferred, with or without a dedicated boiler system.

RECOVERY ALTERNATIVES

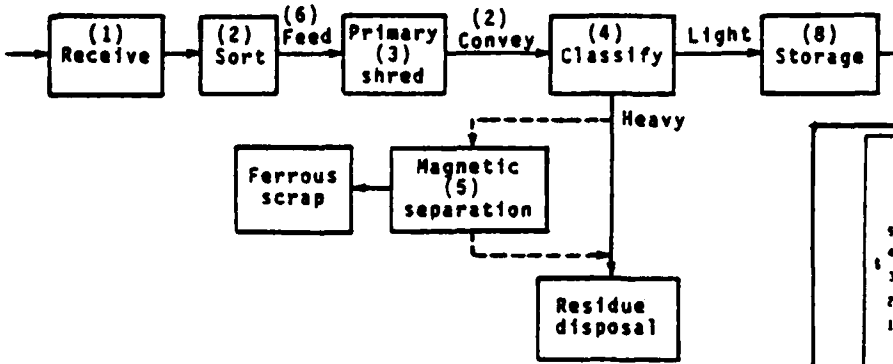
Production Considerations

- Coarse fluff RDF systems are the simplest of the RDF systems in design. Operation and maintenance of requirements are therefore lower and system reliability is higher.
- Some system components currently in use, particularly shredders and air classifiers, are considered most efficient at 50 tons/hr or above. Even small RDF systems often include some large capacity components for this reason. Significant economies of scale exist where this design philosophy prevails.
- All commercial-scale RDF systems on line or planned, have larger design capacities than most Navy installations need.

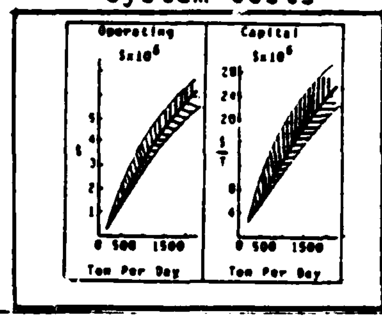
Sale/Use Considerations

- Effective sale of RDF usually required large volume production (>500 tpd) to interest large volume users.
- Regional RDF systems are common, in part because of the need to attract large buyers.
- RDF buyers are unpredictable, because most industries are not familiar with RDF. They may agree to buy it but later decide against it for technical reasons. Test burns and corrosion tests are recommended before negotiations begin.

APPLICABLE TECHNOLOGY



System Costs



Unit operations

Number	Function	Commonly Used Equipment	Reference No
1	Receive	Concrete tipping floor Concrete pit	Not included Not included
2	Sort	Clamshell crane, front-end loader	Not included
3	Primary shred	Horizontal/vertical hammermill	MH-E, MH-F
4	Classify	Vertical/rotary air classifier, ballistic classifier, trommel screen	MH-I, MH-D
5	Magnetic separation	Overhead, electromagnetic, belt magnetic separator	MH-J, MH-K
6	Shredder feed	Primary conveyor	MH-B
7	Materials conveyance	Secondary conveyor	MH-B
8	Storage	Surge bin, silo	MH-A

Personnel Requirements

- 0-250 tpd: one operator, two assistants, one mechanic.
- 250-750 tpd: one operator, three assistants, one mechanic.

Marketability of Product

Coarse fluff RDF has traditionally been difficult to market due to its relatively unrefined condition and the associated high inorganic content. Test burns of coarse fluff RDF at the St. Louis test facility proved successful enough to the local utility for consideration of commercial scale production.

On the other hand,the Tacoma, Washington system does not presently operate at capacity due exclusively to a lack of markets.

Operating Example

- Tacoma, Washington (500 tpd).

Applicability

Military - not feasible in 0-40 tpd range regional - minimum of 200-250 tpd for economic feasibility.

COMPLEMENTARY SYSTEMS

Source separation

- Removal of aluminum cans, tin-coated steel cans, glass containers will enhance fuel processing characteristics (decreased inorganics)
- Removal of office paper, newspaper, corregated cardboard will enhance fuel processing operations but degrade fuel heat content and reduce fuel quantity.
- Removal of tin-coated steel cans will reduce ferrous scrap recovered.

Incinerators/Boilers

- Suspension firing alone of coarse fluff RDF is not recommended in industrial boilers.
- Proper combustion requires a fixed or moving grate for proper burnout of the larger particles.

FUEL MARKETS/USES

Fuel Characteristics

Densified refuse-derived fuel (dRDF) is the extruded form of coarse fluff or fine fluff RDF. It most often takes the form of cylindrical pellets ranging from 1/4 in to 1 in in diameter and up to 3 in in diameter. Because moisture usually serves as the binding agent, the chemical composition is the same as the input RDF.

The dRDF pellets are intended to serve as a fuel substitute for coal in solid fuel-fired combustion systems. Various tests have been performed using dRDF in conventional coal-fired boilers, with mixed results. Violatization is typically slower for the dRDF, and the coal and ash handling systems do not always adapt well to dRDF.

Potential Uses	System Type	Restriction/Limitations
Combustion	Modular incinera-ation	Alone or mixed with raw MSW
	Solid fuel boiler Solid fuel heater	Alone or mixed with original fuel
Refinement	Coal-fired boilers and heaters	d-RDF may have to be re-shredded prior to use
	All	Ash handling system may have to be oversized

System Characteristic	Specification	Typical Range	Important to:
Capacity	Tons/hr	No long-term operating data available	Handle expected waste flow
Capital cost	Dollars/ton		Evaluate cost effec-tiveness
Facility size	Height (ft)x length (ft)x width (ft)		Fit into available space Obtain air pollution operating permits.
Product output			
RDF	Ton RDF/ton MSW Ton scrap/ton MSW		Evaluate operating economics
Ferrous scrap	Ton scrap/ton MSW		
Power consumption	KWH/ton		Compatible with existing system

Demand

Price is a function of:

- Displaced fuel cost and availability.
- RDF quality, quantity, and deliverability (guaranteed/non-guaranteed).
- Future conventional and alternate fuel price trends.
- Technical compatibility of combustion equipment.
- Air pollution control requirements.
- Residue disposal requirements.

As in the case of coarse fluff RDF, dRDF demand is controlled by customer awareness of its composition and combustion characteristics. Densification is considered advantageous for long-term storage (3 to 6 months), but test rusn on burn, storage and handling characteristics are recommended for systems with equipment already in place.

RECOVERY ALTERNATIVES

Production considerations

- dRDF production is 2 steps more complex than fine fluff RDF, and as such is that much more susceptible to maintenance downtime.

- The pellet mills are commonly experience rapid die wear, and have been a high maintenance item in pilot scale systems.

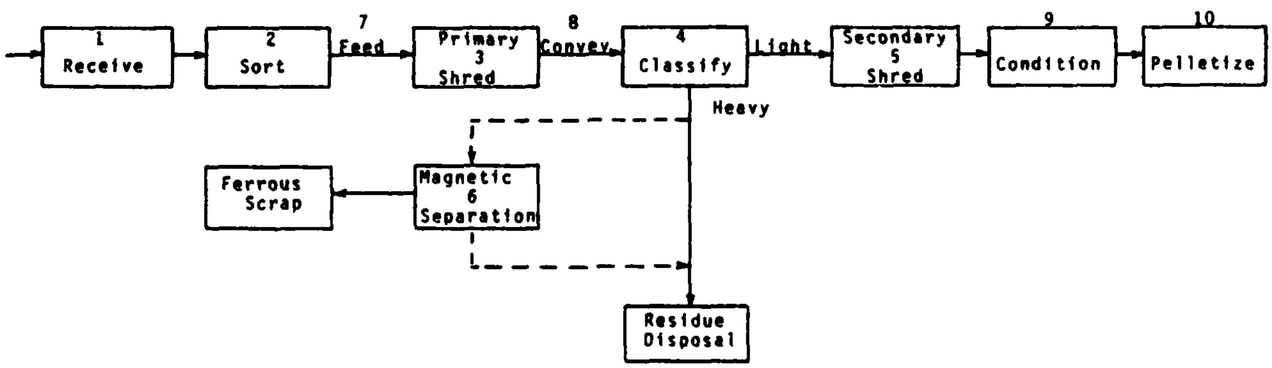
- Because pelletizing is an additional stage which does not produce an associated fuel value (revenue) increase, a captive large volume user is crucial to project success.

- Regional systems are favored, again due to significant economy of scale for processing components.

Sale/Use Considerations

- Same as for coarse fluff scale/use.

APPLICABLE TECHNOLOGY



Unit operations

Number	Function	Commonly Used Equipment (Reference)	Purpose
1	Receive	Concrete tipping floor Concrete pit (not included)	Organize and store incoming refuse
2	Sort	Clamshell crane, front-end loader (not included)	Protect equipment from unprocessibles
3	Primary shred	Horizontal/vertical hammermill (MH-E, MH-F)	Size reduction - homogenization
4	Classify	Vertical/rotary air classifier, ballistic classifier, trommel screen (MH-D, MH-I)	Separation of organics/ inorganics
5	Secondary shredder	Horizontal/vertical hammermill (MH-E, MH-F)	Size reduction
6	Magnetic separation	Overhead, electromagnetic, belt magnetic separator (MH-J, MH-K)	Separation of ferrous scrap/inorganics
7	Shredder feed	Primary conveyor (MH-B)	Conveyance/control raw waste feed
8	Materials conveyance	Secondary conveyor, (MH-B)	Transport of waste from operation to operation
9	Condition	Sprinklers, dryers (not included)	Adjust moisture content
10	Pelletize	Grain press, pellet mill (MH-O)	Reduce bulk density

Personnel Requirements: 0-250 tpd, one operator, two assistants, one mechanic. 250-750 tpd, one operator, three assistants, one mechanic.

Marketability of Product

Lack of commercial experience with dRDF sale and use will hinder marketing efforts. Ongoing test burns at Wright-Patterson AFB and elsewhere should confirm combustion and handling properties, permitting more rapid commercial development,

Operating Examples:

- Baltimore County.
- Other pilot scale demonstrtions.

Applicability

Military - not feasible in 0-40 range.regional - minimum of 200-250 tpd for economic feasibility

COMPLEMENTARY SYSTEMS AND THEIR IMPACT

Source Separation

- Removal of aluminum cans, tin-coated steel cans, glass containers will enhance fuel processing characteristics.
- Removal of office paper, newspaper, corregated cardboard will enhance fuel processing operations but degrade fuel heat content and reduce fuel quantity.
- Removal of tin-coated steel cans will reduce ferrous scrap recovered.

FUEL RECOVERY	Physically Powdered RDF	FR-SF-PP	P. 1 of 3

FUEL MARKETS/USES

Application	System Type	Restriction/Limitations
Combustion	Suspension-fired coal boiler or heater	RDF blended with pulverized coal

Specifications

Characteristic	Specification	Typical Range	Important to:
Capacity	Tons/hour	600-1,400 tpd	Handle expected waste flow
Capital cost	$ per ton/day	Data not available to determine parameters	Evaluate cost effectiveness
Size	Height (ft) x length (ft) x width (ft)		Fit into available space
Particulate emissions	Micro grams/cu meter		Obtain air pollution operating permits
Product output			Evaluate operating economics
RDF	Ton RDF/ton MSW		
Ferrous scrap	Ton scrap/ton MSW		
Power consumption	KWH/ton		Compatible with existing system

Demand

Price is a function of:

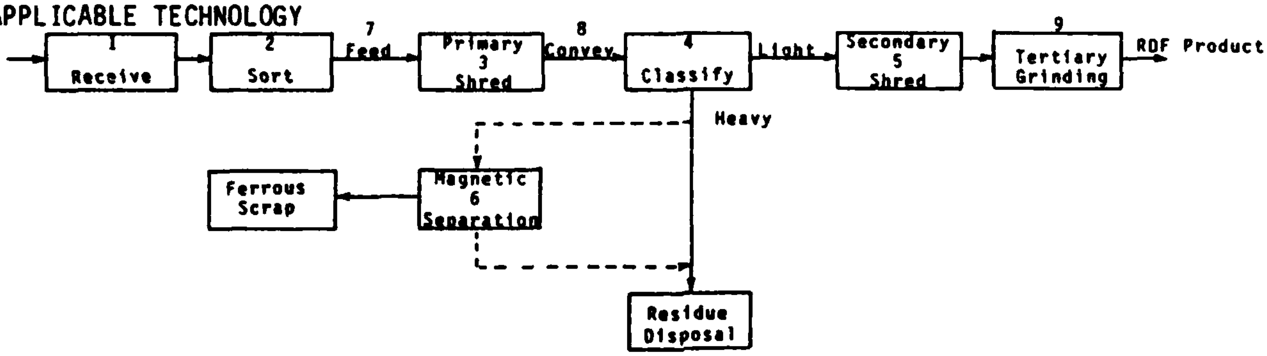
- Displaced fuel cost and availability.
- RDF quality, quantity, and deliverability (guaranteed/non-guaranteed).
- Future conventional and alternate fuel price trends.
- Technical compatibility of combustion equipment.
- Air pollution control requirements.
- Residue disposal requirements.

RECOVERY ALTERNATIVES

Production considerations

Centralize Processing	Regional Processing
Larger capacity systems	Hauling costs are reduced
Provide capital and operating economies of scale	Redundancy is provided
Siting and design is simplified	Surge capacity and operating flexibility increased

APPLICABLE TECHNOLOGY



Unit Operations

Number	Function	Commonly Used Equipment	Purpose
1	Receive	Concrete tipping floor Concrete pit (not included)	Organize and store incoming refuse
2	Sort	Clamshell crane, front-end loader (not included)	Protect equipment from unprocessibles
3	Primary shred	Horizontal/vertical hammermill (MH-E, MH-F)	Size reduction - homogenization
4	Classify	Vertical/rotary air classifier, ballistic classifier, trommel screen (MH-D, MH-I)	Separation of organics/inorganics
5	Secondary shred	Horizontal/vertical hammermill (MH-E, MH-F)	Size reduction
6	Magnetic separation	Overhead, electromagnetic, belt magnetic separator (MH-J, MH-K)	Separation of ferrous scrap/inorganics
7	Shredder feed	Primary conveyor (MH-B)	Conveyance/control raw waste feed
8	Materials conveyance	Secondary conveyor (MH-B)	Transport of waste from operation to operation
9	Tertiary grinding	Ball mill, roller mill (not included)	Size reduction

Personnel Requirements: 0-250 tpd, one operator, two assistants, one mechanic.
250-750 tpd, one operator, three assistants, one mechanic.

Marketability of Product: Operators of suspension-fired coal boilers or heaters.
Operators of fuel oil-fired boilers or heaters.

Operating Example: Bridgeport, Conn.
ECO - Fuel II (1,800 tpd)

The Bridgeport facility has experienced numerous through-put problems throughout its two-year existence. The facility is currently closed due to financial difficulties and the previous two operators do not expect to reopen. The prepared fuel was utilized as designed with no adverse effects. The future of the plant is uncertain.

Applicability:military only - not feasible in 0-40 tpd range regional - minimum of 200-250 tpd for economic feasibility.

COMPLEMENTARY SYSTEMS AND THEIR IMPACT

Source Separation

- Removal of aluminum cans, tin-coated steel cans, glass containers will enhance fuel processing characteristics.
- Removal of office paper, newspaper, corregated cardboard will enhance fuel processing operations but degrade fuel heat content and reduce fuel quantity.
- Removal of tin-coated steel cans will reduce ferrous scrap recovered.

Selective Waste Acceptance

- Waste of commercial origin has more desireable fuel characteristics than waste of residential origin.

FUEL MARKETS/USES

Fuel Characteristics

Low Btu gas produced by pyrolysis consists of a mixture of a wide variety of combustible and non-combustible gases. The exact composition of the gas depends on the composition of the raw material and on the specific process used to convert the raw material to gaseous, liquid, and solid components. In general, a low Btu gas produced by pyrolysis will consist of a mixture of nitrogen, carbon dioxide, carbon monoxide, hydrogen, and methane.

Fuel Uses

Pyrolysis of solid waste requires that heat energy be added to the pyrolysis reactor. In most of the pyrolysis systems that have been proposed, 100 percent of the low Btu gas that is produced has been recycled back to the reactor for this purpose. Gas from a system designed to produce excess gas could be used on-site for steam production or other heating applications. Because of the low heating value and the presence of toxic carbon monoxide in the gas, transport for use offsite is not practical.

RECOVERY ALTERNATIVES

Pyrolysis is the process by which complex organic materials are broken down by heat into a combustible gas, a liquid containing long chain hydrocarbons, and a solid char. The quantity and quality of the gas (as well as the other outputs) are highly dependent on the design and operating conditions of the pyrolysis unit. In systems which produce a low Btu gas, the necessary process heat is commonly provided by partially combusting the waste. The carbon dioxide produced, and the nitrogen in the intake air, are noncombustible and therefore reduce the heating value of the gas.

CURRENT STATE OF DEVELOPMENT

A large-scale (1,000 ton/day) facility for the production and on-site use of pyrolysis gas was constructed in Baltimore, Maryland in 1972-1975. This facility did not operate as designed and was extensively modified in 1976. Additional modifications were performed in 1978, and the system is now shut down for conversion to mass burning incineration. Further development of the pyrolysis technology employed is not anticipated. Significantly more basic research needs to be performed before any full scale facilities are built.

Cost

No cost estimates for small to medium scale facilities are available. The cost of the 1,000 ton/day facility in Baltimore, after adjusting to discount the one-time costs associated with a first of a kind demonstration, was estimated to be $22 million (1977 dollars).

FUEL RECOVERY	Medium Btu Gas (Pyrolysis)	FR-GR-MBP	P. 1 of 1

FUEL MARKETS/USES

Fuel Characteristics

Medium Btu gas produced by pyrolysis consists of a mixture of a wide variety of combustible and non-combustible gases. The exact composition of the gas depends on the composition of the raw material and on the specific process used to convert the raw material to gaseous, liquid, and solid components. Estimates of the characteristics of the gas resulting from three different systems are given below:

Component (% by volume)	Purox System	Enterprise System	Dual Fluidized Bed
H_2	26	1.19 - 4.06	19.58
CO	40	3.53 - 21.25	35.84
CO_2	23	14.80 - 36.36	16.73
CH_4	5	2.31 - 13.69	14.35
Other Hydrocarbons	1	6.07 - 14.18	9.08
N_2 and others	1	17.3 - 72.26	4.08
Heating Value (Btu/SCF)	370	146 - 502	530

Fuel Uses

Pyrolysis fuel gas can be combusted on-site to produce steam. Transporting the gas off-site is limited by the relatively low heating value (as compared to natural gas) and the quantity of toxic carbon monoxide in the gas stream. Carbon monoxide has a heating value of 323 Btu/cu ft, therefore the removal of this component would adversely affect the energy recovery efficiency of the system.

RECOVERY ALTERNATIVES

Pyrolysis is the process by which complex organic materials are broken down by heat into a combustible gas, a liquid containing longer chain hydrocarbons, and a solid char. The quantity and quality of the gas (as well as the other outputs) is highly dependent on the design and operating conditions of the pyrolysis unit. The heat required for pyrolysis can be applied by partially combusting or by indirectly heating the raw material. If a medium Btu gas is desired systems which partially combust the waste must use pure oxygen as the combustion source rather than air. Indirect heating can be achieved by heating the walls and internal mechanisms of the pyrolysis reactor, or by using an intermediary, such as a preheated fluidized bed. The processes in FR-gF-LB demonstrate each of these three alternatives.

CURRENT STATE OF DEVELOPMENT

Pilot and full-scale pyrolysis units have been constructed in several locations in the United States. These facilities have not been successful in demonstrating that pyrolysis technology is ready for wide-spread application to produce energy. Additional research and development is required if pyrolysis is ever to become a viable technology.

For application to Navy facilities, pyrolysis is particularly unsuitable because it is a high technology, capital intensive process in which small to medium-scale plants are impractical.

Cost

No cost data for small to medium-scale pyrolysis plants are available.

FUEL MARKETS/USES

Application/Market	System Type	Restrictions/Limitations
On-site combustion	Space heating, Steam generation, IC engines	Hydrogen sulfide must be removed. Lack of total system reliability would require that alternate energy sources are available, through storage and/or connection to outside sources.
Transport offsite	Sale to utility or local industrial user	Purchaser will limit moisture, hydrogen sulfide, and carbon dioxide. The relatively low heating value (compared to natural gas) makes transport over long distances impractical. See Item 1D, p. 2.
Automotive fuel	Motor pools, delivery vehicles	Vehicles converted to methane have limited driving range between refuelings. A range of 25-50 miles can be expected.

Fuel Specifications

Fuel specifications are divided into specifications for the raw material for the digester, and those for the resulting gas. Specifications for raw material are essential for proper operation of the process, and control of the quality and quantity of gas produced.

Raw Material Characteristics	Desirable Level	Important to:
Generation rate	>40 tons/day	System economics (see Section 4).
Generation rate variability	Uniform generation rate	System performance. Process cannot adjust to rapid increase in input.
Biodegradability	>75% of input	Non-biodegradable materials do not produce gas, but do require processing and disposal.

Resulting Fuel Characteristics	Desirable Level	Important to:
Energy content	>500 Btu/SCF (maintained by controlling digester pH)	Fuel use. Gas with a low energy content has limited use. Equipment modification is possible within a limited range to accommodate low Btu gas.
H_2S content	No H_2S	Any H_2S in gas will cause corrosion of equipment.

Demand

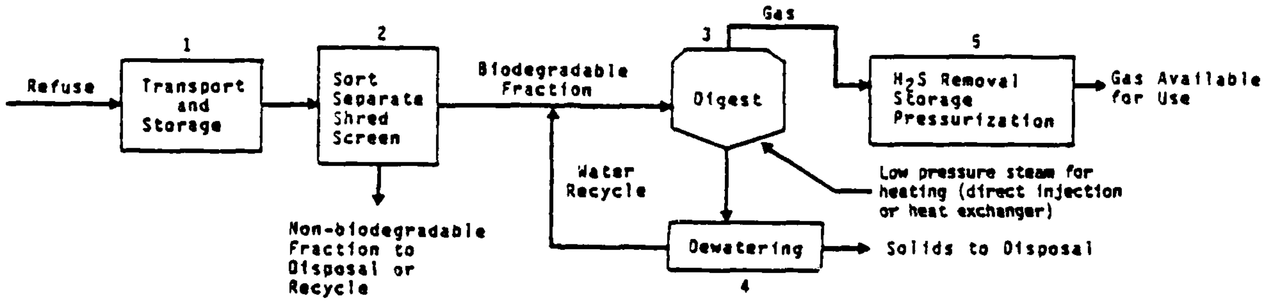
Medium Btu gas produced by anaerobic digestion can be directly substituted for natural gas, usually with only minor modifications to existing equipment. If the digestion process is properly controlled, the resulting gas is clean burning and highly desirable environmentally. The gas typically will have 1/2 the heating

value of natural gas, and therefore be sold for approximately half the cost of that fuel. If the quantity of digester gas is very small (less than 5 percent) of the total quantity of gas used locally, it may be possible to inject the gas into the existing gas pipeline network, without processing to increase the Btu content.

RECOVERY ALTERNATIVES

Anaerobic digestion is the process by which complex organic materials are broken down into carbon dioxide and methane by bacteria which live in an oxygen-free environment. This environment can be maintained in an enclosed digestion tank, which also serves as the collection and short-term storage facility for the product gas. The quantity of gas produced is dependent on the amount of organic material fed to the digester temperature. Temperatures of 90-110°F result in a slower, more easily controlled, digestion of materials. Temperatures of 120-140°F result in a faster, more complete, conversion to gas if system stability can be maintained. Operating temperatures between these two ranges are usually unfavorable because of instability and low conversion efficiency. Most digestion systems operate in the lower temperature range.

APPLICABLE TECHNOLOGY



Number	Function	Commonly Used Equipment	Reference
1	Provide waste on a continuous basis	Compactor vehicles, storage bins, conveyors	MH-B, MH-A
2	Remove recoverable material and non-biodegradable material, reduce size of particles, remove grit	Magnetic separator	MH-J, MH-K
		Aluminum separator	MH-N
		Air classifier	MH-I
		Flail mill	MH-G
		Shredder	MH-F, MH-E
		Screens	MH-C, MH-D
3	Digest organics to methane and carbon dioxide	Anaerobic digester	CE-J
		Mixer	Not included
		Heat recovery system	CE-D
4	Minimize waste treatment costs, recycle essential nutrients to digester	Filter press	Not included
		Centrifuge	Not included
		Vacuum filter	Not included
5	Gas processing to permit use	Depends on intended use of gas	

System Alternatives

The type of equipment necessary in Items 2 and 5 above depend on both economic and technical considerations. Inclusion of a magnetic separator may merely be economically desirable. Inclusion of a trommel screen may, however, be essential technically to permit proper operation of the digester without frequent equipment breakdown due to grit.

Other alternatives to be considered would be the inclusion of sewage sludges and municipal refuse from surrounding areas in a larger, regional facility.

Cost

Application of the relatively complex energy recovery system shown above to navy facilities is limited by size constraints. Currently available equipment is not sized for small-scale systems. The operating labor costs also make small-scale systems impractical. The estimated cost for a 100 ton/day facility is $5 million (1981 dollars). Additional costs for disposal of non-biodegradable materials and dewatered solids must be added.

State of Development

A 100 ton/day anaerobic digester for municipal refuse is currently being tested by Waste Management, Inc., at their solid waste disposal facility at Pompano Beach, Florida. After initial start-up problems associated with separation of inorganic fines from the input stream, the system is performing as anticipated. A test program to determine optimum operating temperature, feed rate, retention time, and the requirements for front-end processing is underway. Data are not yet available on the results of this work.

Technology transfer from other processes somewhat reduces the requirements for additional research and development work. The front-end processing of municipal solid waste is common to many resource recovery options. Anaerobic digestion of sewage sludges has been common for many years, as has the dewatering of sludges.

COMPLIMENTARY SYSTEMS

Anaerobic digestion for energy production can be enhanced by an preprocessing which reduces the inorganic content of the feed material. Overall system economics are usually improved by the inclusion of metal recovery, making this option highly advantageous. Removal of other inorganics through the use of screens, air classifiers, hand sorting, source separation, etc., may not provide economically recoverable materials, but decreases both the required size and maintenance for the digester and following units.

Increased digestion efficiency can be obtained by increasing digester temperature. This can be accomplished quite easily if the gas is used on-site by using the waste heat from boilers or the cooling water from IC engines to heat the digester.

FUEL MARKETS/USES

Fuel Characteristics and Uses

Anaerobic Digester inputs and resulting gas quality/quantities:

Characteristics of feed stock to processing	Typical Base Activity Type: Food Service	Exchange or Commissary	Barracks	Offices	Storage/ Warehouse
Approximate generation rate (per day)	0.87-1.47 (lb/meal)	133 (lb/ 1000ft^2)	0.3 (lb/ person)	2.54 (lb/ person)	2.36 (lb/ 1000ft^2)
% Organic	83-95%	96-99%	77-96%	75-99%	94-97%
% Biodegradable	59-95%	70-95%	71-82%	63-93%	45-93%

Characteristics of Resulting Fuel Gas	Food Service	Exchange or Commissary	Barracks	Offices	Storage/ Warehouse
Methane content (%)	95%	95%	95%	95%	95%
Carbon Dioxide content (%)	5%	5%	5%	5%	5%
Btu value (Btu/scf)	950	950	950	950	950
Conversion efficiency (Approximate percentage of organic material converted to gas.)	30-45%	35-45%	35-40%	30-45%	25-45%
Energy recoverable (per day)	1,600-3,500 (Btu/Meal served)	240,000-325,000 (Btu/ 1,000ft^2)	540-740 (Btu/ person)	4,600-6,300 (Btu/ person)	4,200-5,800 (Btu/ 1,000ft^2)

Application/Market	System Type	Restrictions/Limitations
On-site combustion	Space heating, Steam generation, IC engines	For most on-site use, processing digestor gas to pipeline quality would be impractical. Better energy recovery would be possible by using the gas without removing carbon dioxide.
Transport offsite	Sale to utility or local industrial user	Normal supply/demand factors would apply.
Automotive fuel	Motor pools, delivery vehicles	Vehicles converted to methane have limited driving range. A range of 50-100 miles can be expected.

Fuel Specifications

Fuel specifications are divided into specifications for the raw material for the digester, and those for the resulting gas. Specifications for raw materials are essential for proper operation of the process, and control of the quality and quantity of gas produced.

Raw Material Characteristics	Desirable Level	Important to:
Generation rate	>100 tons/day	System economics (see Section 4)
Generation rate variability	Uniform generation rate	System performance. Process can not adjust to rapid increase in input
Biodegradability	>75% of input	Non-Biodegradable materials do not produce gas, but do require processing and disposal.

Resulting Fuel Characteristics	Desirable Level	Important to:
Energy content	>900 Btu/Scf	Compatatability with existing gas supply
Pressure	200-1,000 PSI (III)	Match pressure of existing long distance pipelines
Moisture	Less than saturated	Reduce corrosion and improve heating value
H_2S content	None present	Reduce corrosion

Demand

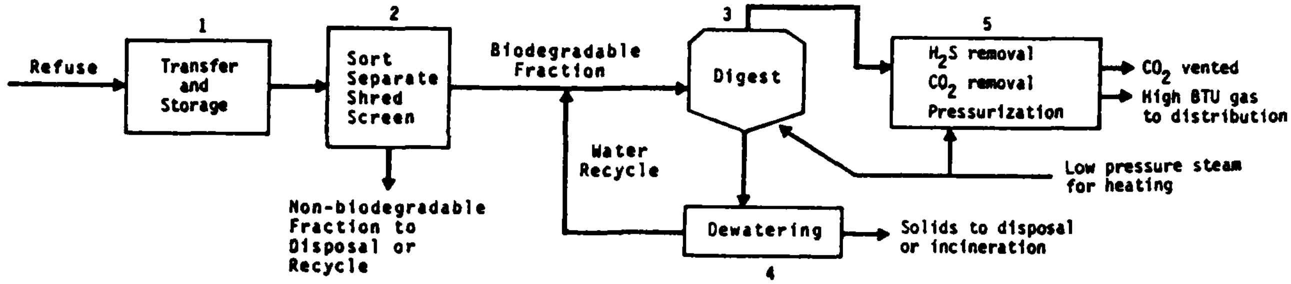
If digester gas is processed to increase its heating value, the resulting methane is perhaps the most highly desirable source of energy that can be produced from solid waste The gas can be directly substituted for existing natural gas supplies, with no modifications to equipment. Existing storage and distribution systems can also be used. Environmentally, methane is virtually an ideal fuel, producing only carbon dioxide and water vapor upon combustion.

RECOVERY ALTERNATIVES

Anaerobic digestion is the process by which complex organic materials are broken down into carbon dioxide and methane by bacteria which live in an oxygen-free environment. This environment can be maintained in an enclosed digestion tank, which also serves as the collection and short-term storage facility for the product gas. The quantity of gas produced is dependent on the amount of organic material fed to the digestor, the residence time in the digester, and digester temperature. Temperatures of 90-110°F result in a slower, more easily controlled digestion of materials. Temperatures of 120-140°F result in a faster, more complete conversion to gas if system stability can be maintained. Operating temperatures between these two ranges are usually unfavorable because of instability and low conversion efficiency. Most digestion systems operate in the lower temperature range.

High Btu gas is produced by removing the carbon dioxide from the digester gas. Several technologies for this process have been developed, with large-scale facilities in operation to cleam up natural gas supplies.

APPLICABLE TECHNOLOGY



Number	Function	Commonly Used Equipment	Reference No.
1	Provide waste on a continuous basis	Compactor vehicles, storage bins, conveyors	MH-A, MH-B
2	Remove recoverable material and non-biodegradable material reduce particle size, remove grit	Magnetic separator	(MH-J, MH-K)
		Air classifier	(MH-I)
		Aluminum separator	(MH-M)
		Flail mill	
		Shredder	(MH-E, MH-F)
		Screen	
3	Digest organics to methane and carbon dioxide	Anaerobic digester	(MH-J)
		Mixer,	
		Heat recovery system	(CE-D)
4	Minimize waste treatment costs, recycle essential nutrients	Filter press	Not included
		Centrifuge	Not included
		Vacuum filter	Not included
5	Produce pipeline quality gas	Acid gas removal system	Not included

System Alternatives

The type of equipment necessary in Items 2, 4, and 5 above depend on both economic and technical considerations. Extensive sorting and classification will improve digester performance. If sludge is dewatered sufficiently it can be incinerated to produce the required process steam. The type of gas clean-up system selected is highly dependent on the volume of gas processed.

Cost

Application of the complex energy and resource recovery system shown above to navy facilities is impractical due to size constraints. Currently available equipment is not sized for small systems. The operating labor costs also make small system impractical. Larger, regional facilities, processing 1000 tons/day of refuse, can be operated economically. The projected capital expenditure for a system of this size is $14-20 million.

FUEL MARKETS/USES

Pyrolysis oil can be processed into a variety of organic chemicals and feed stocks, including benzene, toluene, xylene, napthalene, resins, and gasoline substitutes. Alternatively, the pyrolytic oil can be burned as a replacement for heavy or light fuel oil without refining. The characteristics of the pyrolytic oil depend on the type of raw waste input to the system and the operating parameters of the pyrolysis unit. A heavy oil resembling No. 6 fuel oil can be produced (the Garrett, or Occidental process) or a lighter oil, similar to No. 2 fuel oil (the Enterprise pyrolysis system). Characteristics of oil from the Enterprise test unit are shown below. The test was performed with selected Navy waste consisting primarily of paper and plastic materials from Port Hueneme, California.

Sulfur	0.02%	Viscosity SSU	35.1 @ 100°F
Heat content	18,730 Btu/lb		25.1 @ 210°F
Gravity API @ 60°F	26.9	Water & Sediment	1.8%
Flash point	194°F	Water	0.3%

RECOVERY ALTERNATIVES

Pyrolysis is the process by which complex organic materials are broken down by heat into a combustible gas, a liquid containing long-chain hydrocarbons, and a solid char. The quantity and quality of the liquid fuel produced by pyrolysis depends on the design and operating conditions of the pyrolysis unit. The longer the residence time in the pyrolysis reactor, and the higher the temperature in the reactor, the heavier the oil produced by pyrolysis.

CURRENT STATE OF DEVELOPMENT

The Garrett process, which was developed in cooperation with the Occidental Research Corporation, was used in a 200 tons/day demonstration plant constructed in El Cajon, California. Several major process problems were discovered, but financial support to modify the system was unavailable. Plant operations have been suspended.

A 150 tons/day system by the Enterprise Company was constructed for testing and development at South Gate, California in 1976. Testing and evaluation continued through 1978 when operations were terminated. No further development has occurred.

Cost

No detailed cost estimates are available for small to medium-scale installations applicable to Navy facilities. The Garrett process was developed under partial support of the U.S. EPA, with an estimated initial cost of $15 million. The Enterprise system was developed with private funds, with the amount not disclosed.

FUEL RECOVERY	Gasoline	FR-LF-GS	P. 1 of 1

FUEL MARKETS/USES

The fuel produced by the purification and polymerization of pyrolysis gas can be refined into a gasoline like substitute fuel. This fuel can be used directly in gasoline engines or mixed with other supplies. The quantity of gasoline produced by this process has been estimated at approximately 42 gallons per ton of refuse.

RECOVERY ALTERNATIVES

Pyrolysis systems can be designed and operated in a manner which increases the quantity of olefins (hydrocarbons with double carbon bonds) in the pyrolysis gas, and decreases the quantity of other pyrolysis products. The gas is then separated into components, and the olefins polymerized into gasoline. Alternatively, the synthetic crude oil produced by other pyrolysis systems can be refined into gasoline.

STATE OF DEVELOPMENT

The bench-scale process for producing olefin-rich pyrolysis gas included the grinding of the refuse to .01-in diameter, injection of steam, and rapid heating to approximately 1300°F. The gas can then be cleaned to remove the char, and the olefins separated out. The olefins can then be converted to a gasoline substitute.

The conversion process described is only in its early development. Short-term bench-scale tests have been carried out, but no pilot or full-scale plans have been developed. More basic research, economic analysis, and testing is required before the process can be considered a viable recovery alternative. Additional data are not available.

REFERENCES

Diebold, James P., "Gasoline From Solid Wastes by Noncatalytic, Thermal Process", in Thermal Conversion of Solid Wastes and Biomass, Jerry L. Jones and Shirley B. Radding, editors, ACS Symposium Series #130, American Chemical Society, Washington, D.C., 1979.

SECTION IV

COMBUSTION SYSTEMS

Combustion systems (CS), the third and final system category presented in this report, is limited to those systems which consume a solid waste-derived fuel to produce an energy product (steam, hot water, hot gas, and/or electric power).

Subsections are presented for each of the following systems (codes are shown in parentheses):

- Solid fuel (SF)
  - Modular incinerators (MO)
  - Pulverized (PV)
  - Stokers (SF)
  - Fluidized bed (FB).
- Liquid fuel (LF)
  - Light fuel oil (LO)
  - Light fuel oil/solid slurry (LS)
  - Heavy fuel oil (HO)
  - Heavy fuel oil/solid slurry (HS)
  - Internal combustion engine (IC).
- Gaseous fuel (GF)
  - Low-Btu gas/natural gas mixture (LB)
  - High-Btu gas/natural gas mixture (HB)
  - Gas turbines (GT).

The content of the combustion system subsections provides equal emphasis on the marketing and technical aspects, under the following major headings:

- Product markets: product characteristics, uses, and specifications.
- Applicable technology: general description, unit operations, alternative configurations, cost.
- Complementary systems and their impact.

Some systems are considered developmental, and the subsection detail is reduced as appropriate. In these instances, a subsection entitled, "Stage of Development," replaces "Applicable Technology."

PRODUCT MARKETS

Product Characteristics

Product	Range of Characteristics	Output/ton of solid waste
Steam	100-280 psig, saturation	3,700 lb/ton (average)
Hot water	No use reported 150-500°F expected	Data not available
Hot gases	No use reported up to 1600°F expected	Data not available
Electric power	No use reported 200-1000 KWH expected	Data not available 30-100 KWH per ton expected 0.008-0.027 KWH/lb steam expected

Product end uses, specifications

End Use	Average Btu/sq ft/yr (000)	Hot water Gal/sq ft/yr	Steam (lb/sq ft/yr)	Electrical (KWH/sq ft/yr)	Considerations
Offices:	55	336.4	39.5	6.1	A B C (all uses) D,E,G,
Hospital	160	974.0	115.1	46.8	D,E,G
Training Facility	50	304.4	36.0	14.6	D,E,F,H
Housing Family	82	499.2	59.0	24.0	D,E,I
BOQ	61	371.3	43.9	17.9	D,E,I
Storage	50	34.4	36.0	14.6	D,E,J
Service	95	578.3	68.3	27.8	D,E,K

Considerations

A. Budgets listed include a 45% energy reduction as mandated by E.O.12003 for new facilities. Existing facilities for which waste derived energy is being considered will have energy demands exceeding the values listed.

B. Hot water system calculations assumes 20°F temperature drop across radiator. 180°F input. For 30°F drop 2/3 the listed quantity would be required, a 10°F drop would require 2 times the listed quantity.

C. Based on metered rate for electrical energy. Generated rate would require approximately 3.4 times listed figure.

D. Demands listed are heating and cooling loads only. No process energy is supplied.

E. Values listed are heating and cooling loads based on national averages and typical building of this type. Local requirements will vary.

F. Nonworking hour loads will be substantially lower in most cases.

G. Noninterruptable supply is critical.

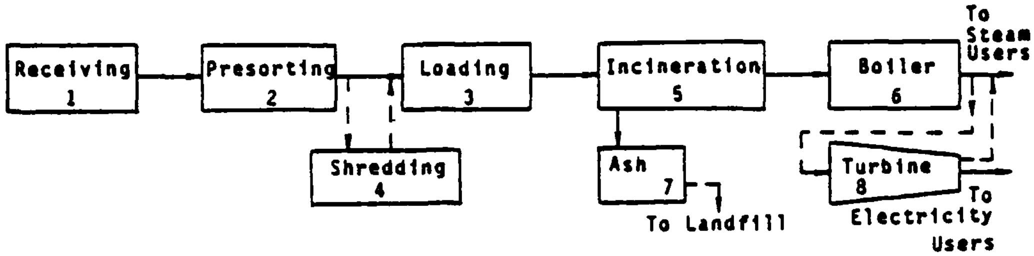
H. Demand will fluctuate widely with facility use patterns.

I. Demand will be 24 hour.

J. Cold storage facilities have approximately 2 times the demand as valves listed.

K. Includes laundry/dry cleaning, and commissary facilities.

APPLICABLE TECHNOLOGY



Unit operations

Number	Function	Commonly Used Equipment	Reference No.
1	Receiving area	Tipping floor, pit, front-end loader	Not included
2	Presorting area	Front-end loader, crane, manual	Not included
3	Loading	Manual-batch, hydraulic ram-batch, charging hopper-batch, conveyor-continuous	MH-B
5	Incineration	Incinerator	CE-A
6	Steam generation	Waste heat boiler	CE-D
7	Ash removal	Quench pit, water spray conveyor	Not included

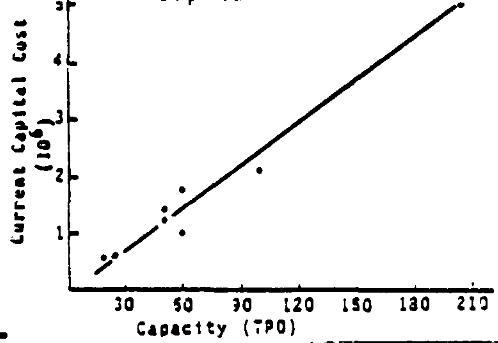
Alternative Approaches

- Shredding; preprocessing by shredding can increase combustion efficiency by reducing particle size and increasing surface area for combustion.
- Electrical generation; ease of transport of product (electricity) and universal nature and relatively constant level of demand are plus factors. With extraction type turbine steam is released at approximately 110 psig. high pressure steam, >400 psig, is needed. Higher capital cost for equipment.

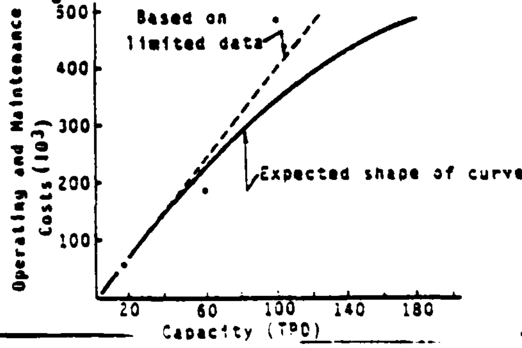
Number	Function	Commonly Used Equipment	Reference No.
4	Size reduction	Shredders	MH-E, MH-F
8	Electricity generation	Extraction turbine, backpressure turbine	Not included

System Costs

Capital



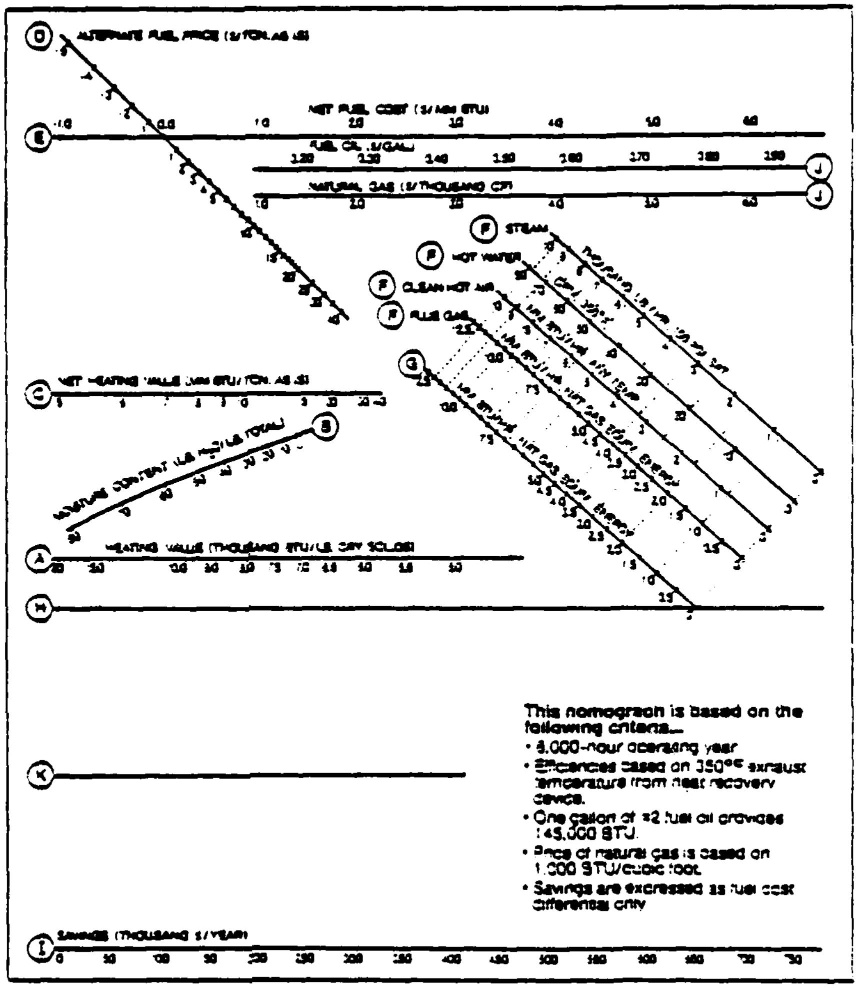
Operating and Maintenance



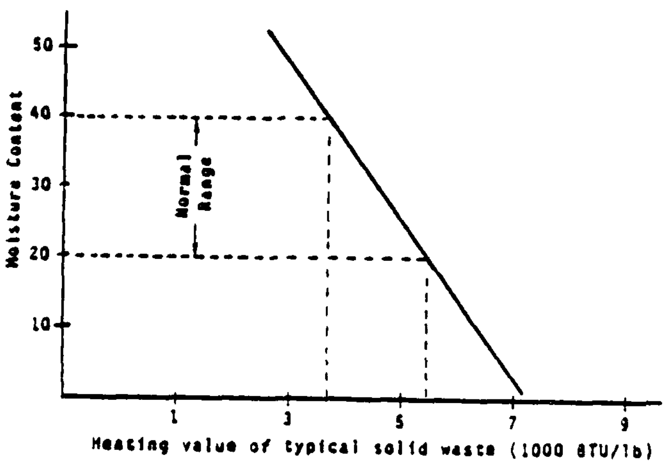
System Efficiency

Nomograph Use Procedure

1. Locate on line A the heating value (Btu/# dry solids) of your alternate fuel. Typical heating values of solid waste are given in the graph below.
2. Locate on line B the moisture content of the solid waste fuel.
3. Draw a straight line through the alternate fuel heating value (line A) and moisture content (line B) to line C to determine the net heating value of one ton of alternate fuel.
4. Locate the price of the alternate fuel on line D.
5. Draw a straight line through the net heating value (line C) and price (line D) to line E to determine the net cost of alternate fuel in $/MM Btu.
6. Select your particular energy requirement or a multiple thereof from one of the four lines labeled F.
7. Transfer the energy requirement to line G by following the grid lines. Line G expresses your requirement in terms of MM Btu/hr natural gas equivalent energy.
8. Draw a straight line through the alternate fuel cost (line E) and energy requirement (line G) to line H.
9. Draw a straight line connecting the point on line H to the zero point on the left end of line I. This line intersects line K and the intersection point will be used in Step 13.
10. Locate the price currently being paid for fuel oil or natural gas on one of the lines labeled J.
11. Trar 'er the fuel price on line J to line E. This number represents your current fuel price expressed in $/MM Btu.
12. Draw a straight line through your current fuel cost (line E) and energy requirement (line G) to line H.
13. Draw a straight line to line I through the point determined in Step 12 and the intersection point previously established on line K (Step 9). The point located on line I by Step 13 gives a direct reading of annual fuel savings only. Multiply savings by scale factor is used in Step 6.



Nomograph supplied by:
Thermal Processes, Inc.
Olympia Fields, Il. 60461



COMPLEMENTARY SYSTEMS

Material Separation

- Removal of noncombustible components from the waste stream can benefit the operation of a packaged incinerator facility by increasing the net heating value of the feed on a per pound basis.

- Removal of the glass fraction can aid in preventing slagging of the bottom and ash removal grates, which has been a common problem in systems of this type.

Initial Size Reduction

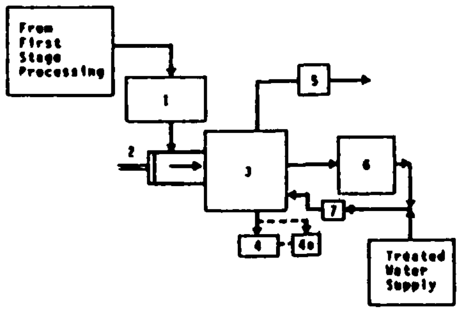
- Preprocessing by shredding or other means may benefit an incineration system by improving combustion and burnout, and reduce the quantity of residue needing disposal. These economic tradeoffs associated with preprocessing have not been well defined.

PRODUCT MARKETS

Product Characteristics

Product	As Designed	As Experienced	Output Quantity/Ton of Solid Waste
Steam	150-350 psig	100-300 psig	5,700 pounds
Electricity	500-600 kWh	400-500 kWh	400 kWh
Hot water	150-300°F	100-300°F	70-150 gpm

APPLICABLE TECHNOLOGY



Unit Operations

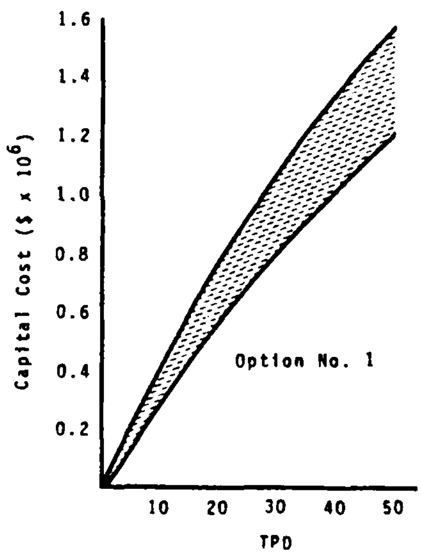
Number	Function	Typical Equipment	Reference
1	Receive	Live bottom bin	MH-J
		Primary shred (ferrous, AL, and glass free)	MH-E, MH-I, MH-L
2	Feed	Ram feeder (hydraulic)	Not included
3	Incinerator/ boiler	Solid waste (refractory lined/ waterwall) boiler (steam or hot water	CE-L, CE-O
4	Residue (manual dump)	Ash handling system (batch removal from ash pit)	Not included
4a	Continuous dumping	Ash handling system (drag chain conveyor in quench pit)	Not included
5	Pollution control	Baghouse, cyclone, or ESP	APC-A, APC-B, APC-C
6	Steam users	Load centers, as buildings, etc.	
7	FW return	Feed water (FW) return or supply system (pumps, water treatment, generator, feed water heater, etc.)	N/A

Alternative System
Unit Operations

Number	Function	Typical Equipment (Alternative System)
1'	Receive	Live bottom bin (fine shred material) RDF storage and retrieval.
2'	Feed	Pneumatic blowing of fine shredded RDF
3'	Incinerator/boiler	Dedicated boiler; semi-suspension firing (or) co-firing with coal, spreader-stoker firing
4'	Residue	Continuous ash dump, quench and drag chain ash removal, straining and hauling
5'	Pollution control	Baghouse, or ESP
6'	Steam user	Heating steam to building, etc.
7'	F.W. return	100% condensate return, water make-up or 100% treated water make-up
8'	Steam drive	Steam turbine (solar, Terry)
9'	Elec. generator	Electrical generator system

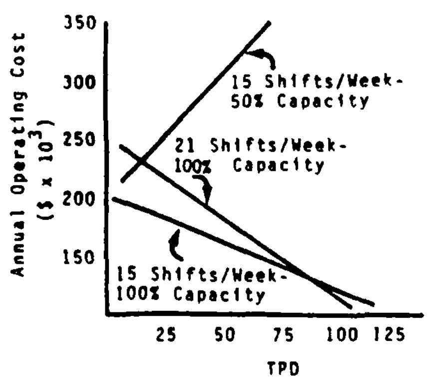
Capital Costs - One Time Items

Equipment	% of Total
Site: Preparation, fence, land-scaping	1.3
Building, foundation, steel, concrete	9.4
Incinerator/boiler, ID fan, pollution control, ash system	68.2
Pumps and drive	0.4
Water treatment	1.0
Process control panel	
Stack and support	0.8
Construction and installation of equipment	7.2
Utilities (water, electrical, fuel, steam)	1.7
Engineering	9.6
	100.0



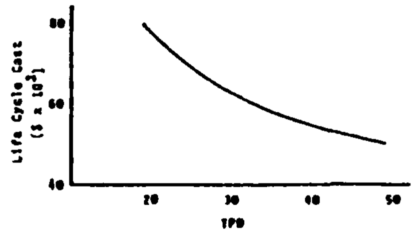
Capital Costs - (Maximum Value)

Equipment	Tpd - $ x 10^3 (1980) 1980 $ 20	30	50
Site Prep & Land-scaping	9.4	13.0	19.6
Building, founda-tion, concrete	68.0	94.1	141.6
Incinerator/boiler ID fan, pollution control, ash sys.	493.7	682.9	1,027.7
Pumps & drives	3.0	4.0	6.0
Water treatment	7.2	10.0	15.1



COMBUSTION SYSTEMS	Pulverized Refuse Incinerator	CS-SF-PV	P. 3 of 4

Process control panel	3.0	4.0	6.0
Stack & support	5.8	8102.1	
Construction, etc.	52.1	72.1	108.5
Utilities	12.3	17.0	25.6
Engineering	69.5	96.1	144.7
Total Plant Facilities Invest. (PFI)	724.0	1,001.2	1,506.9
Startup & organ. (5% of PFI)	36.2	50.0	75.3
Total Capital Invt.	760.2	1,051.2	1,582.2



Costs - Recurring (Annual) (\$ x 10^3 - 1980 \$)

Item	20	30	50
Labor	90.1	13.1	90.1
Residue	8.8	13.1	21.9
Electricity	3.5	5.3	8.8
Oil (trucks & startup)	13.7	20.6	34.3
Water	1.8	3.2	5.0
Maintenance supplies (2% PFI)	14.5	20.0	30.1
Maintenance labor (2% PFI)	14.5	20.0	30.1
Chemical/ water treatment	1.6	3.8	5.2
Admin Overhead (15% labor)	13.5	13.5	13.5
Total Operaing Cost	162.0	189.6	290.0

Basis of Operating Cost Calculations

Labor: 2 men/1st shift; 1 man/2nd shift 16 hr/day (0.75 x 365) days/year \$20,800/ year cost of labor - including benefits.

Equivalent of 4-1/3 people's cost.

Elec. \$0.04/kWh; 1.0 kW/tpd

Oil: 40 gpd at \$1.25/gallon

Water: Assume 100% make-up, 10% blow down plus 8 gal/ton for ash quench and clean up.

Labor cost includes substitute people needed to meet leave and emergency. Capital costs not included

Net Operating Cost = Total operating cost minus credit as tipping fee, salvage of ferrous, aluminum, and glass and energy cost credit for steam or electricity.

Residue = .4 x tpd x \$4/ton

NOTE: For plants of 1 to 2 tph capacity, the labor and administration costs are approximately constant. Operating costs/ton decrease when plant is operating 3 shifts/day, 365 days/year. The realistic hours of operation are calculated here.

COMPLIMENTARY SYSTEMS - OPTION #2

The Option #2 consists of (1) pneumatic feeding of fine shredded refuse (2 stage shredding vs. single stage shredding of Option #1) and, (2) electricity generation instead of using the steam for process and building heating.

Cost Factors (Option #2)

1. Pneumatic feeder	Rotating screw type
2. Pneumatic fan	50 hp motor drive
3. Pneumatic transport line	10" diameter
4. Installations	

	20 TPD	30 TPD	50 TPD
Plant Facilities Investment (PFI) Option #2A ($ 1980)	$749 x 10^3	$1,033.7 x 10^3	$1,554.4 x 10^4

Option #2B - Electrical Generation

1. Steam turbine (non-condensing)
2. Generator
3. Controls, switchgear, and transformer
4. Pipeline, installation, and bldg.

	20 TPD	30 TPD	50 TPD
Plant Facilities Investment (PFI) Option #2B ($ 1980)	$759 x 10^3	$1,042 x 10^3	$1,042 x 10^3

Operating Costs ($ 1980)	20 TPD	30 TPD	50 TPD
Option #2A - Same as Option #1			
Option #2B (Additional over Option #1)			
Labor/1 man extra shift x 2 shift/day + relief = 3=1/2 m	$72.8 x 10^3	$72.8 x 10^3	$72.8 x 10^3
Maintenance supplies (2% PFI)	0.7 x 10^3	0.8 x 10^3	1.2 x 10^3
Maintenance labor (2% PFI)	0.7 x 10^3	0.8 x 10^3	1.2 x 10^3
Admin. or Head (15% labor)	10.9 x 10^3	10.9 x 10^3	10.9 x 10^3
(Additional Cost over cost for Option #1)	$85.1 x 10^3	$85.3 x 10^3	$86.1 x 10^3

Comments

For small solid waste plant (1 to 2 tph), a modular solid waste boiler (type Basic Env. Eng. Co's unit or equivalent) is adequate. For such an incinerator/boiler single stage shredding with ram feeding of the primary shredded refuse is the best option. Generation of electricity is not recommended with saturated steam. For small boilers, superheated steam, although possible to generate, is not very common.

16 hours/day of operation is quite adequate. The boiler can be banked for the night and started again in the morning. The manpower estimated is minimum.

REFERENCES

1. "Materials and Energy from Municipal Waste," published by the Office of Technology Assessment, Washington, D.C., July 1979.
2. "Thermal Processing of Municipal Solid Waste for Resource and Energy Recovery," Weinstein and Toro, Ann Arbor Science, Publisher.
3. "Small Modular Incinerator Systems with Heat Recovery," EPA Publication #SW/77C, November 1979.

COMBUSTION SYSTEMS	Stoker Boiler	CS-SF-SF	P. 1 of 4

PRODUCT MARKETS

Product Characteristics

Product	As Designed	As Experienced	Output Quantity/Ton of Solid Waste
Hot water	150-300°F	100-300°F	200°F 70-150 gpm
Steam	150-300 psig	100-300 psig and saturated	5,400 lb sat at 300 psig
Electricity	500 kW	400 kW	385 kW

Product end uses, specifications

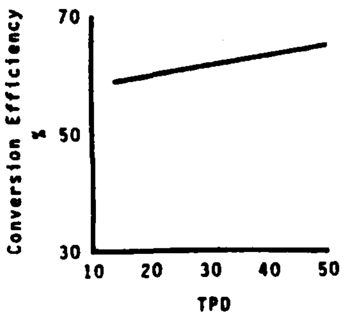
End Use	Average Btu/sq ft/yr (000)	Hot water Gal/sq ft/yr	Steam (lb/sq ft/yr)	Electrical (KWH/sq ft/yr)	Considerations
Offices:	55	336.4	39.5	16.1	ABC (all uses) D,E,G,
Hospital	160	974.0	115.1	46.8	D,E,G
Training Facility	50	304.4	36.0	14.6	D,E,F,H
Housing Family	82	499.2	59.0	24.0	D,E,I
BOO	61	371.3	43.9	17.9	D,E,I
Storage	50	34.4	36.0	14.6	D,E,J
Service	95	578.3	68.3	27.8	D,E,K

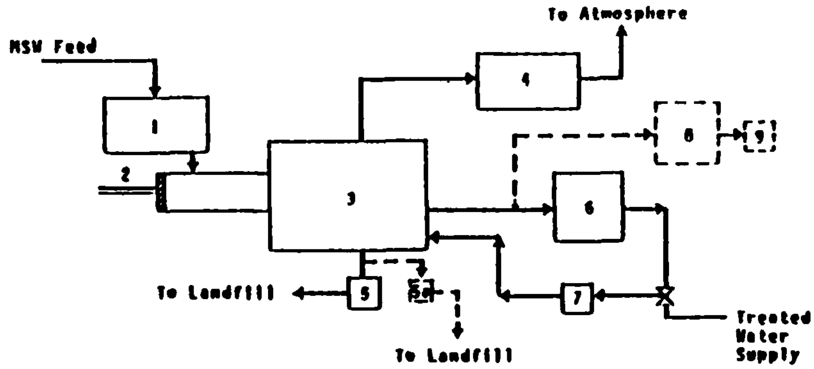
Considerations

A. Budgets listed include a 45% energy reduction as mandated by E.O.12003 for new facilities. Existing facilities for which waste derived energy is being considered will have energy demands exceeding the values listed.
B. Hot water system calculations assumes 20°F temperature drop across radiator. 180°F input. For 30°F drop 2/3 the listed quantity would be required, a 10°F drop would require 2 times the listed quantity.
C. Based on metered rate for electrical energy. Generated rate would require approximately 3.4 times listed figure.
D. Demands listed are heating and cooling loads only. No process energy is supplied.
E. Values listed are heating and cooling loads based on national averages and typical building of this type. Local requirements will vary.
F. Nonworking hour loads will be substantially lower in most cases.
G. Noninterruptable supply is critical.
H. Demand will fluctuate widely with facility use patterns.
I. Demand will be 24 hour.
J. Cold storage facilities have approximately 2 times the demand as values listed.
K. Includes laundry/dry cleaning, and commissary facilities.

COMBUSTION SYSTEMS	Stoker Boiler	CS-SF-SF	P. 2 of 4

APPLICABLE TECHNOLOGY





Unit Operations

Number	Function	Typical Equipment	Reference
1	Receive	Live bottom sorted raw refuse receiver bin (as discarded MSW)	MG-H Not included
2	Ram feed	Ram feeder (hydraulic)	
3	Incinerator/ boiler	Solid waste incinerator/boiler unit (steam or hot water, travelling grate)	CE-G
4	Pollution control	Baghouse or cyclone	APC-A, APC-B
5	Residue	Manual dump ash bin and removal system	Not included
6	Steam user	Heating and/or process steam or hot water user points	N/A
7	Boiler feed	Feed water supply (return) system including pump, heatup, and treatment	N/A

Alternative System

Number	Function	Description
1	Receive	Primary shred; Fe, aluminum and glass free MSW
2	Ram feed	Ram feeder (hydraulic)
3	Incinerator/ boiler	Solid waste incinerator/boiler unit (steam or hot water, travelling grate)
4	Pollution control	Baghouse or cyclone
5	Residue	Manual dump ash bin and removal system
5A	Residue - Alt.	Continuous discharging ash dumping, quencing and handling system
6	Steam user	Heating and/or process steam or hot water user points
7	Boiler feed	Feed water supply (return) system including pump, heatup, and treatment
8	Steam drive	Steam turbine (non-condensing)
9	Electrical energy	Turbine-driven electrical generator system

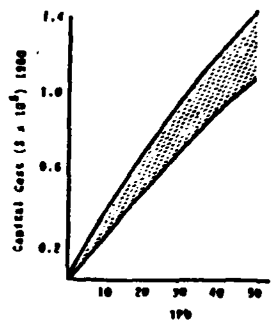
COMBUSTION SYSTEMS	Stoker Boiler	CS-SF-SF	P. 3 of 4

Costs - Capital - (Max Value Basis)

Tpd - ($ x 10^3) (1980 - 4th Quarter)

Equipment	20	30	50
Site prep., etc.	8.3	11.7	17.87
Building, foundation concrete	60.2	84.6	129.25
Incinerator/boiler ID fan, pollution control, ash handling	436.5	613.8	937.75
Pumps & drive	2.6	3.6	5.50
Process control equipment			
Stack & support	5.1	7.2	11.0
Construction	46.1	64.8	99.0
Utilities	10.8	15.3	23.38
Engineering and supervision	61.4	86.4	132.0
Total plant facilities investment (PFI)	640.0	900.0	1,375.0
Startup & Organ. (5% PFI)	32.0	45.0	68.8
Total capital investment	672.0	945.0	1,443.8

Basis of calculations
Base case - 50 tpd



Costs - Recurring - (Operating per year) (See graph on Page 4.)

Item	20	30	50	Remarks
Labor	114.4	114.4	114.4	Equivalent of 5 1/2 people
Residue haul	9.9	14.8	24.6	Residue = 0.45 (wet) refuse and $4/ton for hauling cost
Electricity	3.5	5.3	8.8	
Water	1.8	3.2	5.0	
Chemical	1.6	3.8	5.2	Elec.: $0.04/kWh; 1.0 kW/Tpd
Oil	6.8	10.2	17.0	(20 x 16 H/D x 365 x .75 D/Yx.04)
Maintenance supplies (2% PFI)	12.8	18.0	27.5	Water: Assume 100% makeup, 10% blow down plus 8 gal/ton for ash quench and clean up.
Maintenance labor (2% PFI)	12.8	18.0	27.5	
Admin. overhead (15% labor)	17.2	17.2	17.2	Labor cost includes substitutue people to meet summers, leave, and emergency.
Total operating cost	168.0	204.9	247.2	Net operating cost = actual operating cost. (Credit tipping fee, salvage of ferrous, alum., glass) and energy cost credit for steam or electricity.)
Operating cost/ton/yr ($ x 10^3)	$8.4	$6.83	$4.94	

Capital Cost - Complementary System

- Steam turbine.
- Generator.
- Controls, switchgear, and transformers.
- Piping and installations.

COMBUSTION SYSTEMS	Stoker Boiler	CS-SF-SF	P. 4 of 4

	20 Tpd	30 Tpd	50 Tpd
Estimated cost (Plant facilities investment)	675 x 10^3	\$940.8 x 10^3	\$1,435.1 x 10^3
Operating cost (additional)			
Labor 1 man/shift x 2 shifts x factor for relief men	\$72.8 x 10^3	\$72.8 x 10^3	\$72.8 x 10^3
Maintenance supplies (2% PFI)	0.7 x 10^3	0.8 x 10^3	1.2 x 10^3
Maintenance labor (2% PFI)	0.7 x 10^3	0.8 x 10^3	1.2 x 10^3
Admin. overhead (15% labor)	10.9 x 10^3	10.9 x 10^3	10.9 x 10^3
Total additional cost	\$85.1 x 10^3	\$85.3 x 10^3	\$86.1 x 10^3

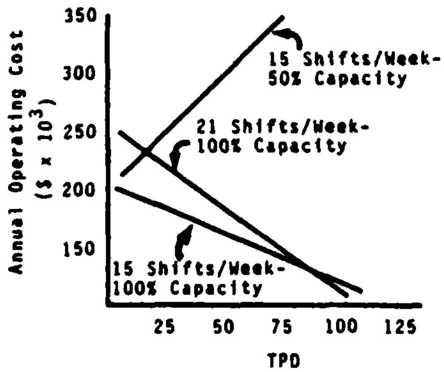
Comments

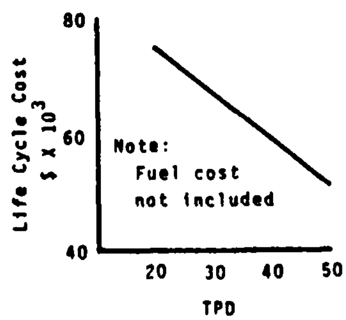
Several different types of mechanical stokers are commonly used in processing solid wastes as shown and described below. However, for solid waste processing plants of 1 to 2 TPH capacity, a travelling grate type system is generally adopted. For 200 to 400 TPD plants, both reciprocating and rocking grate type stokers have been extensively used.

Stoker-fired units can handle both processed and unprocessed solid wastes. Normally, for spreader-stoker firing, processed solid waste fuel is fed onto the traveling grate and incinerated as it travels through the furnace. The stoker typically consists of a large grate occupying 100% of the cross-sectional area of the furnace. Forced draft and overfire air are supplied through the grates and walls over the solid waste bed. At the end of the grate, a conveyor is used to remove the ash.

REFERENCES

1. J. Jones, et al, "Mass Burning of Refuse in Shop Fabrication Incinerator," prepared by SRI International, for Civil Engineering Laboratory, U.S. Naval Construction Battalion, Port Hueneme, CA, October 1979.
2. "Solid Wastes," by G. Tehobanoglous and Theisen, McGraw-Hill Book Company.
3. "Small Modular Incinerator Systems with Heat Recovery," EPA Publication No. SW177C.





PRODUCT MARKETS

Product Characteristics

Product	As Designed	As Experienced	Output Quantity/Ton of Solid Waste
Hot water	150-300°F 1-5 atm	100-300°F 1-3 atm	200-100 gpm
Hot gases	100-200°F	N/A	400-2,000 SCFM
Steam	250 and 350 psig and saturated	150 and 300 psig and saturated	6,250 lb
Electricity			638 kW

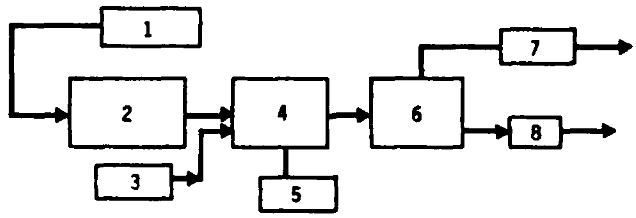
Product end uses, specifications

End Use	Average Btu/sq ft/yr (000)	Hot water Gal/sq ft/yr	Steam (lb/sq ft/yr)	Electrical (KWH/sq ft/yr)	Considerations
Offices:	55	336.4	39.5	16.1	ABC (all uses) D,E,G,
Hospital	160	974.0	115.1	46.8	D,E,G
Training Facility	50	304.4	36.0	14.6	D,E,F,H
Housing Family	82	499.2	59.0	24.0	D,E,I
Bachelor	61	371.3	43.9	17.9	D,E,I
Storage	50	34.4	36.0	14.6	D,E,J
Service	95	578.3	68.3	27.8	D,E,K

Considerations

A. Budgets listed include a 45% energy reduction as mandated by E.O.12003 for new facilities. Existing facilities for which waste derived energy is being considered will have energy demands exceeding the values listed.
B. Hot water system calculations assumes 20°F temperature drop across radiator. 180°F input. For 30°F drop 2/3 the listed quantity would be required, a 10°F drop would require 2 times the listed quantity.
C. Based on metered rate for electrical energy. Generated rate would require approximately 3.4 times listed figure.
D. Demands listed are heating and cooling loads only. No process energy is supplied.
E. Values listed are heating and cooling loads based on national averages and typical building of this type. Local requirements will vary.
F. Nonworking hour loads will be substantially lower in most cases.
G. Noninterruptable supply is critical.
H. Demand will fluctuate widely with facility use patterns.
I. Demand will be 24 hour.
J. Cold storage facilities have approximately 2 times the demand as valves listed.
K. Includes laundry/dry cleaning, and commissary facilities.

APPLICABLE TECHNOLOGY



Unit Operations

Number	Function	Typical Equipment	Reference
1	Receiving	Processed RDF receiving bin	Not included
2	Feeder	Hydraulic or equivalent ram	Not included
3	Air handling	Fluidizig air handling system	Not included
4	Combustor	Atmos/pressurized fluidized bed combustor	CE-C, CE-D
5	Residue	Residue removal system	Not included
6	Waste heat recovery	Waste heat boiler	CE-G
7	Pollution control	Baghouse or electrostatic precipitator	APC-A, APC-C
8	Heating steam users	Buildings and process heat users	N/A

System Alternatives

Number	Operation	Description	Reference No.
1	Air heating	Air heating system	Not included
2	Steam drive	Steam turbine	CE-F
3	Electrical generation	Steam turbine-driven generator	CE-F

Unit	Operations	Comments
1	Receiving	Fluidized bed combustor's feed should preferably be inert free (glass, metals, and nonmetals) and shredded. A front-end processing system, consisting of shredding, air classification, trommeling operations, has to be adopted. For continuous operation the prepared receiving bin should have the capacity of 2 days of processing load.
4	Air handling	To maintain fluidizing inert bed temperature the air should be preheated.
6	Residue removal	Could be made automatic and continuous or intermittent and manual operation.

Option #1

Fuel preparation Fe and AL recovery, FBC, steam generation and heating load supply.

Refuse storage space for 72 hr of operation. Oversize material sorting and landfill disposal, mixed glass cullets and contaminated organics to landfill.

Option #2

Fuel preparation, metal recovery, FBC, steam generation, electric power generation, steam and power supply.

Steam at 150 psig - at saturation for Option 1 Steam at 300 psig and saturation expanding to 100 psig for heating load (Option 2 - co-generation, if selected)

Costs -(See graphs on Page 4.)

- Plant operating manpower
  - 10-50 TPD - 14 (3 shifts)
  - 50-100 TPD - 18 (3 shifts)
  - Over 100 TPD - 21 (3 shifts).
- In view of the fact that no commercial or municipal atmospheric fluidized bed combustors are in operation with MSW as feedstock, reliable operating costs could not be projected. Pilot plant data reveal 10 to 15% less cost when compared to conventional incineration system.

Design & Construction Cost Estimate Plant Investment Cost (Typical 50 TPD	Thousands of $ (4th Quarter 1980)	Remarks
Site Preparation	53.4	Cost of an atmospheric fluidizing bed combustor consisting of front-end processing facilities
Buildings	340.6	
Front-end processing equipment including shredder, air classifier, magnetic separator, trommel, Al, recovery, storage and retrieval	297.4	
Atmos. fluidized bed combustor	120.7	
Waste heat boiler	68.3	
Ash handling equipment	35.8	
Pollution control equipment	107.2	
Material handling system	97.3	
Boiler accessories and treatment	79.7	
Engineering	130.6	
Construction	119.3	
Utilities	47.7	
Contingencies	172.0	
Total	$\$1.67 \times 10^6$	

- A fluidizing bed combustor and waste heat boiler system can attain:
  - Combustion efficiency greater than 90%
  - Overall thermal efficiency greater than 70%
  - Energy loss to surroundings less than 30%.

COMPLEMENTARY SYSTEMS

Separation of Materials

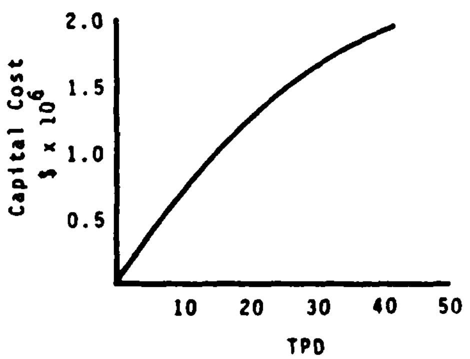
- Resource recovered (for sale): Ferrous, aluminum.
- Resource utilized: Cellulose stocks as paper and paper products. Organic stocks as food wastes, grass, wood, leather.
- Refuse discarded: Mixed colored glass, stone, dirt, and other inerts.

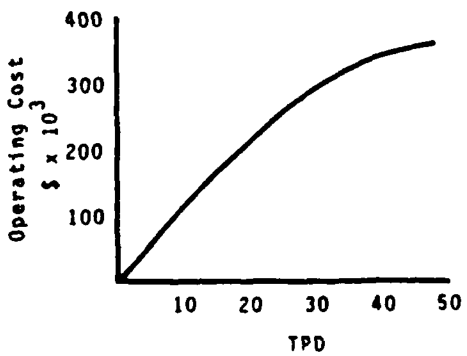
Comments, Notes

Atmospheric fluidized bed combustors have been operated to a limited extent with sewage sludges, wood and biomass products. However, many attempts of using MSW as feedstocks have not been very successful. The glass contents of the processed refuse, the high volatile matter content of MSW and other characteristics of MSW are not conducive to AFBC method of conversion process. DOE and EPA may be funding for demonstration projects this year (1981). (With Combustion Power Systems, ERCO, and Argonne National Laboratory.)

REFERENCES

1. L. Pruitt and Wilson, "Atmospheric Fluidized Bed Combustion of Municipal Solid Waste: Test Program Results." Presented at the Sixth International Conference on Fluidized Bed Combustion, Atlanta, Georgia, April 1980.
2. N. Newell, et al, "Energy Recovery from Municipal Solid Waste Utilizing Fluidizing-bed Technology." Presented at the 9th ASME National Waste Processing Conference, Washington, D.C., May 1980.





PRODUCT MARKETS

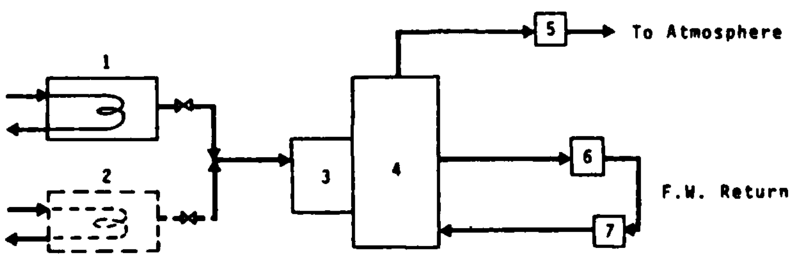
Product Characteristics

Product	Range of Characteristics As Designed	Range of Characteristics As Experienced	Output Quantity/Ton of Solid Waste
Hot water	150-300°F at 1-5 atm	150-250°F at 1-4 atm	25-85 gpm*
Steam	150-275 psig and saturated	100-250 psig and saturated	3,000 lb/hr*
Electricity			320 kW**

* Based on 36 gal of oil/ton of refuse oil - and 4.1×10^6 Btu/ton of refuse. Efficiency: 78%, effective enthalpy of steam = 1,060 Btu/lb.

** 9.4 lb steam/kW.

APPLICABLE TECHNOLOGY



Unit Operations

Number	Function	Typical Equipment	Reference
1	Storage	Refuse-derived pyrofuel oil storage with heater	Not included
2	Storage	Residual fuel oil (optional or dual firing)	Not included
3	Heat source	Duel-oil burner assembly with controls	CE-J
4	Steam	Boiler (hot water or steam)	CE-G
5	Pollution control	Scrubber	APC-D
6	Supply	Steam to users points (heating)	N/A
7	Feed	Feed water system for boiler	N/A

Costs - Capital - One Time Items (4th Quarter 1980)(See graph on Page 4.)

Equipment and Cost Factors	TPD - ($ x 10^3) 20**	30**	50**	Comments
Building, foundation & concrete	24.1	33.4	50.3	The capital cost of modular boiler fitted with gas/oil burner is a func- of heat release rate or the capacity and the heat content of the fuel being fired.
Site preparation	3.6	4.9	7.5	
Boiler, burner, F.D. fan & stack	150.1	207.7	312.6*	
Pumps	1.3	1.8	2.7	
Water treatment	1.0	1.4	2.1	
Boiler control fuel panel	3.3	4.6	6.9	
Pollution control	19.5	27.0	40.7	
Construction & supervision	16.4	22.4	33.7	
Utilities installation	13.9	19.2	28.9	
Engineering	23.9	33.3	49.9	
Total plant facilities investment (PFI)	257.1	355.7	535.3	
Organization & startup (5%)	12.9	17.8	26.8	
Interest of money	Omitted for Fed Project			
Depreciation of equipment				
Total	270.0	373.5	562.1	

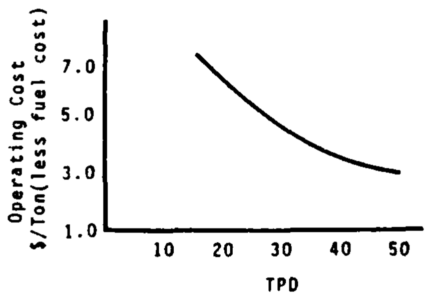
* Boiler cost - $50,000/# steam/hr 3,000 lb steam/ton of refuse/hr.

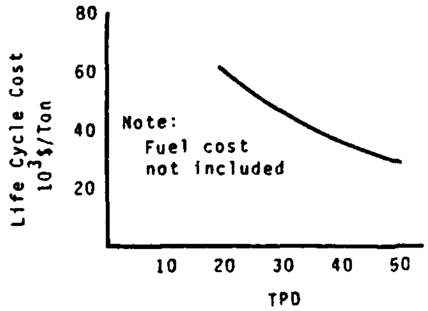
Costs - Recurring - (Operating per year)(See graph on Page 4.)

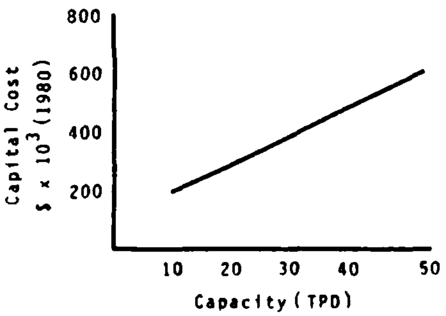
Equipment (Boiler System Only)	20	30	50	Remarks
Labor	90.1	90.1	90.1	1, 2, 5
Electricity	3.5	5.3	8.8	
Water	1.8	3.2	5.0	
Oil (trucks & startup)	6.8	10.3	17.2	
Chemical waste treatment	1.6	3.8	5.2	
Maintenance supplies	5.2	7.1	10.7	
Maintenance labor	5.2	7.1	10.7	
Admin. overhead	13.5	13.5	13.5	
Total	127.7	140.4	161.2	
Operating cost ($/ton)	6.38	4.67	3.22	

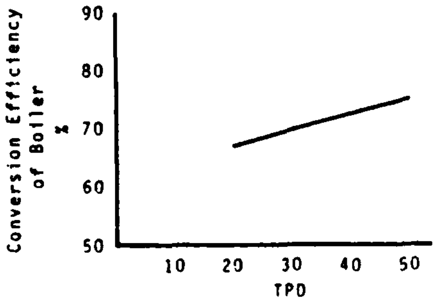
COMBUSTION SYSTEMS	Light Fuel Oil	CS-LF-LO	P. 4 of 4

3. "Small Modular Incinerator Systems with Heat Recovery," EPA No. SW117C, November 1979.
4. "Power Plant Eng. and Design," by Morse, McGraw-Hill.
5. "Mission Analysis for the Federal Fuels from Biomass Program," SRI International, Vol. IV, 1979. Final Report DOE.









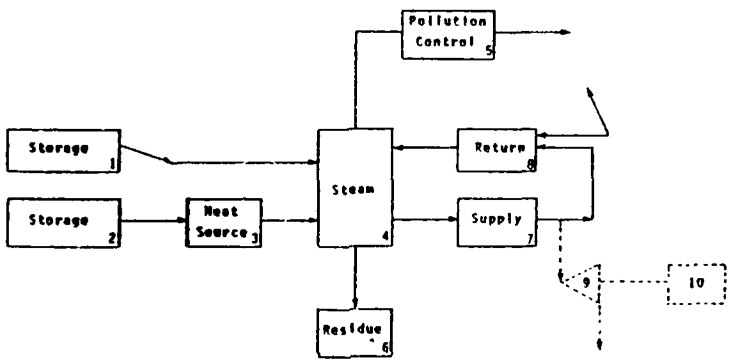
COMBUSTION SYSTEMS	Light Fuel Oil/ Solid Slurry	CS-LF-LS	P. 1 of 3

PRODUCT MARKETS

Product Characteristics

Product	As Designed	As Experienced	Output Quantity/Ton of Solid Waste
Hot water	150-300°F at 1-5 atm	100-250°F at 1-4 atm	20-100 gpm
Steam	100-300 psig	100-300 psig	4,800 lb/ton
Electricity	9.4 lbs STM/kW	9.4 lbs STM/kW	510 kW/ton

APPLICABLE TECHNOLOGY



Unit Operations

Number	Function	Typical Equipment	Reference
1	Storage	MSW receiving and storage (processed/unprocessed)	MH-J
2	Storage	Pyrofuel storage and distribution	Not included
3	Heat source	Fuel oil burner	CE-H
4	Steam	Solid waste boiler	CE-G
5	Pollution control	Optional (controlled air unit - none required)	APC-A, APC-C,APC-D
6	Residue	Ash handling and disposal	Not included
7	Supply	Heating steam users	N/A
8	Return	Feed water system for boiler	Not included

System Alternatives

Number	Operation	Description	Option #2
9	Steam drive	Steam turbine (non-condensing)	Produce steam and generate electricity to supply power to process train drives.
10	Electrical power	Turbine-driven electrical generator	

Reference

1. J. Jones, et al, "Mass Burning of Refuse in Shop Fabrication Incinerator," Prepared by SRI International for U.S. Navy, Civil Eng. Laboratory, Oct. 1979 SRI International.

Costs - Capital - One Time Items (4th Quarter 1980) Option #1 (See graph on Page 3.)

TPD - ($ x 10^3)

Cost Factors	20	30	50*
Site preparation	8.6	11.9	17.9
Building, foundation and concrete	57.8	79.9	120.3
Incinerator/boiler burner, fans steam	359.1	496.7	747.5
Pumps & drives	3.1	4.2	6.4
Combustion controls	8.0	11.0	16.6
Water treatment	2.5	3.4	5.2
Pollution control	46.7	64.6	97.3
Construction	38.7	53.5	80.6
Utilities	33.1	45.8	69.0
Engineering and inspection	57.2	79.2	119.2
Total plant facilities investment (PSI)	614.4	850.2	1,280.0
Startup & organization (5% PSI)	30.7	42.5	64.0
Total	645.1	892.7	1,344.0

* This unit is similar to solid waste boiler with ash removal system plus burners for pyrofuel.

(50% Oil & 50% MSW) (See graph on Page 3.)	20	30	50
Labor	$90.1	$90.1	$90.1
Residue handling	5.0	8.0	12.0
Electricity	3.5	5.3	8.8
Oil	13.7	20.6	34.3
Water	1.8	3.2	5.0
Chemical (water treatment	1.6	3.8	5.2
Maintenance supplies (2% PFI)	12.3	17.0	25.6
Admin overhead (15% labor)	13.5	13.5	13.5
Maintenance labor (2% PFI)	12.3	17.0	25.6
Total	$153.8	$178.5	$220.1
Cost ($/ton)	$7.69	$5.95	$4.40

COMPLEMENTARY SYSTEMS (OPTION #2)

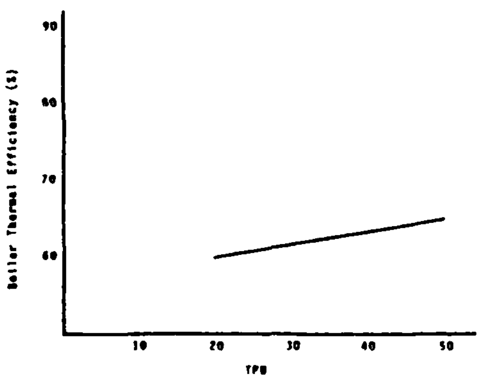
High pressure steam above 300 psig can be utilized to generate electricity or to drive process equipment or to generate electrical power. For power generation the estimated installed cost of the turbo-generator set, transformer, switchgear, etc. is $50,000 (1980 dollars).

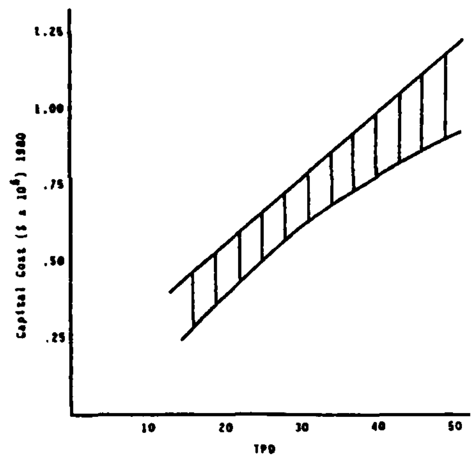
Comments, Notes

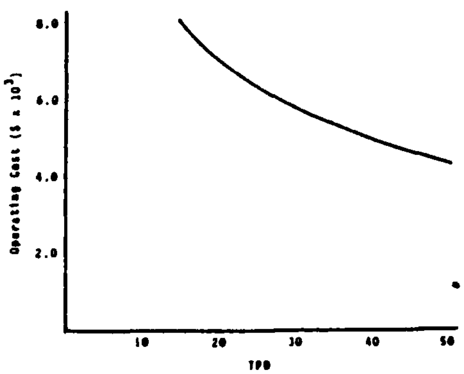
The pyrofuel can be used in conjunction with solid waste by spraying over the waste inside the combustion chamber. An expensive burner may not be required. For a controlled air modular unit the pyrofuel can be used for the secondary combustion chamber to sustain combustion of unburned hydrocarbon gases, as well as, in the primary chamber to keep the combustion chamber hot. The oil heat may be utilized to vaporize the moisture from the solid waste (inside the combustion chamber).

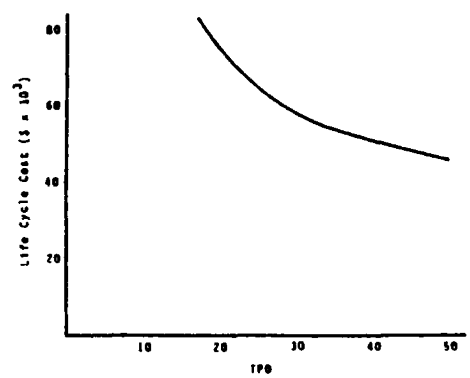
REFERENCES

1. "Thermal Processing of Municipal Solid Waste for Resource and Energy Recovery," by Weinstein and Toro.
2. Personal Communication with Basic Environmental Eng. (verbal quotation).
3. "Small Modular Incinerator Systems with Heat Recovery" - EPA No. SW117C, November 1979.
4. "Power Plant Eng. and Design," by H. Morse, McGraw-Hill.
5. "Mission Analysis for the Federal Fuels from Biomass Program," SRI International, Vol. IV, 1979. Final Report DOE.









Note: Fuel cost not included

PRODUCT MARKETS

Product Characteristics

Product	Range of Characteristics: As Designed	Range of Characteristics: As Experienced	Output Quantity/Ton of Solid Waste
Hot water	Up to 425°F normally up to 250°F, 160 psig.	Heavy oil boilers in these ranges do exist, number firing waste fuels unknown.	Data not available, see Fuel Recovery.
Steam	Up to 900°F, 1650 psig, normally limited to 900°F, 1 to 75 psig.		
Cogeneration of electricity	Up to 15 MW		

Product end uses, specifications

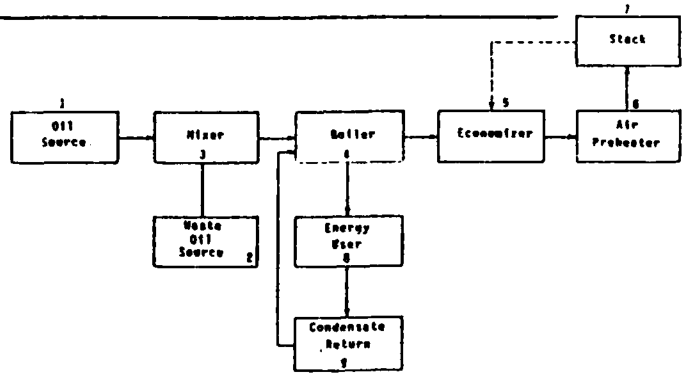
End Use	Average Btu/sq ft/yr (000)	Hot water Gal/sq ft/yr	Steam (lb/sq ft/yr)	Electrical (KWH/sq ft/yr)	Considerations
Offices:	55	336.4	39.5	16.1	ABC (all uses) D,E,G,
Hospital	160	974.0	115.1	46.8	D,E,G
Training Facility	50	304.4	36.0	14.6	D,E,F,H
Housing Family	82	499.2	59.0	24.0	D,E,I
BOQ	61	371.3	43.9	17.9	D,E,I
Storage	50	34.4	36.0	14.6	D,E,J
Service	95	578.3	68.3	27.8	D,E,K

Considerations

A. Budgets listed include a 45% energy reduction as mandated by E.O.12003 for new facilities. Existing facilities for which waste derived energy is being considered will have energy demands exceeding the values listed.
B. Hot water system calculations assumes 20°F temperature drop across radiator. 180°F input. For 30°F drop 2/3 the listed quantity would be required, a 10°F drop would require 2 times the listed quantity.
C. Based on metered rate for electrical energy. Generated rate would require approximately 3.4 times listed figure.
D. Demands listed are heating and cooling loads only. No process energy is supplied.
E. Values listed are heating and cooling loads based on national averages and typical building of this type. Local requirements will vary.
F. Nonworking hour loads will be substantially lower in most cases.
G. Noninterruptable supply is critical.

H. Demand will fluctuate widely with facility use patterns.
I. Demand will be 24 hour.
J. Cold storage facilities have approximately 2 times the demand as values listed.
K. Includes laundry/dry cleaning, and commissary facilities.

APPLICABLE TECHNOLOGY



Unit Operations

Number	Function	Typical Equipment	Reference No.
1	Oil source	Tanks	Not included
2	Waste oil source	Tanks	Not included
3	Mixer	Mixer	Not included
4	Boiler	Firetube or water tube	CE-G
5	Economizer	Fired tube	Not included
6	Air preheater	Regenerative heaters	Non included
7	Stack	Stack and possible cyclone	Not included
8	Energy user	Space heater	N/A
9	Condensate return	Water treatment system	Not included

System Alternatives

Number	Operation	Description	Reference No.
1	Oil source	Drums	Not included
5	Economizers	Increase overall thermal efficiency.	Not included
6	Air Preheaters	Increase overall thermal efficiency.	Not included
7	Cyclone	ESP or air pollution control equipment may be required.	APC-C, APC-B APC-C, APC-D

Unit	Operations	Comments
3	Mixer	Premixed could be bought or separate supply lines could be employed.
4	Boiler	Firetube below about 15,000 lb steam/hour Watertube above this; larger firetube units and smaller watertube are not uncommon.

Costs - Capital - One Time Items (capacity in 10^3 lb/hr steam, cost in $000).

Equipment	Capacity 12	25	130	Reference	System Efficiency
Equipment cost	$103	$265	$919	T. Devitt et al., "Population and Characteristics of Industrial/Commercial Boilers in the U.S.," EPA 600/7-79-178a, August 1979.	System for mixing waste oil with heavy oil not included
Installation cost	168	224	388		
Engineering	27	49	131		
Construction expense	27	49	131		
Construction fees	27	49	131		
Startup	8	13	30		
Contingencies	72	130	346		
Subtotal	432	779	2,076		
Land	3	3	6		
Working capital (fuel excluded)	70	81	151		
Total	$505	$863	$2,233		

Costs - Recurring

Equipment	Capacity 12	25	130	Reference	System Efficiency
Labor and supervision	$174	$174	$335	T. Devitt, et al, "Population and Characteristics of Industrial/Commercial Boilers in the U.S.," EPA 600/7-79-178a August 1979	80 to 88 percent depends if there are economizers or air preheaters
Maintenance	68	75	149		
Electricity	16	35	56		
Steam	17	35	56		
Water	1	1	3		Operating of waste oil heavy oil system not included
Chemicals	3 (14%)	3 (4%)	7 (14%)		
Total	279	323	606		
Overhead					
Payroll	52	52	100		
Plant	63	65	126		
Capital charges					
G&A, and insurance	17	31	83		
Capital recovery	60	109	291		
Total (fuel)	$419	$590	$1,224		

Comments - Notes

The system is assumed to be a normal residual oil boiler in which some waste oils may be fired. Any special problems associated with the oil must be decided on a case-by-case basis. The ash content of the waste oil must not be too different from that of normal residual oil. The waste oil should be first treated to remove particulate matter. Luber-finer systems have been used to clean lube oils before mixing. Dirt can plug burner nozzle. Also boiler is not designed to handle large ash levels.

COMBUSTION SYSTEMS	Heavy Fuel Oil/ Solid Slurry	CS-LF-HS	P. 1 of 4

PRODUCT MARKETS

Product Characteristics

Product	Range of Characteristics: As Designed	Range of Characteristics: As Experienced	Output Quantity/Ton of Solid Waste
Hot water	Up to 425°F normally up to 250°F, 160 psig.	Heavy fuel oil-coal coal slurries tested in utility boilers; unknown where heavy fuel oil/solid waste slurries have been used.	Data not available, see Fuel Recovery
Steam	Up to 900°F, 1,650 psig normally limited to 900°F, 1,075 psig.		
Cogeneration of electricity	Up to 15 MW		

Product End Uses, Specifications

End Use	Average Btu/sq ft/yr (000)	Hot water Gal/sq ft/yr	Steam (lb/sq ft/yr)	Electrical (KWH/sq ft/yr)	Considerations
Offices:	55	336.4	39.5	16.1	ABC (all uses) D,E,G,
Hospital	160	974.0	115.1	46.8	D,E,G
Training Facility	50	304.4	36.0	14.6	D,E,F,H
Housing Family	82	499.2	59.0	24.0	D,E,I
BOO	61	371.3	43.9	17.9	D,E,I
Storage	50	34.4	36.0	14.6	D,E,J
Service	95	578.3	68.3	27.8	D,E,K

Considerations

A. Budgets listed include a 45% energy reduction as mandated by E.O.12003 for new facilities. Existing facilities for which waste derived energy is being considered will have energy demands exceeding the values listed.

B. Hot water system calculations assumes 20°F temperature drop across radiator. 180°F input. For 30°F drop 2/3 the listed quantity would be required, a 10°F drop would require 2 times the listed quantity.

C. Based on metered rate for electrical energy. Generated rate would require approximately 3.4 times listed figure.

D. Demands listed are heating and cooling loads only. No process energy is supplied.

E. Values listed are heating and cooling loads based on national averages and typical building of this type. Local requirements will vary.

F. Nonworking hour loads will be substantially lower in most cases.

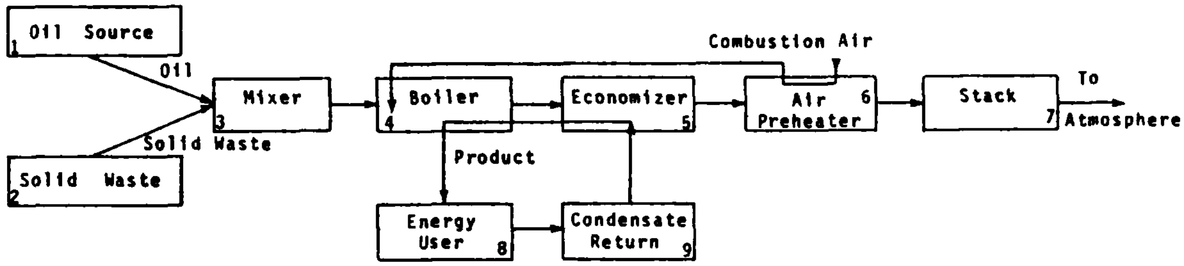
G. Noninterruptable supply is critical.

H. Demand will fluctuate widely with facility use patterns.

I. Demand will be 24 hour.

J. Cold storage facilities have approximately 2 times the demand as valves listed
K. Includes laundry/dry cleaning, and commissary facilities.

APPLICABLE TECHNOLOGY



Unit Operations

Number	Function	Typical Equipment	Option #1
1	Oil source	Tank	Not included
2	Solid waste	Pile	N/A
3	Mixer	Pulverized and mixer	Not included
4	Boiler	Firetube or watertube-tube spacing and furnace size dependent on ash content	CE-G
5	Economizer	Fired tube if ash content is low	Not included
6	Air preheater	Regenerative heater	Not included
7	Stack	Stack and cyclone	Not included
8	Energy user	Space heater	N/A
9	Condensate return	Water treatment system	Not included

System Alternatives

Number	Operation	Description
1	Oil source	Drums.
3	Mixer	Buy ready mixed slurries and thus not needed.
5	Economizer	Increase overall thermal efficiency.
6	Air preheater	Increase overall thermal efficiency.
7	Cyclone	ESP, wet scrubber, possibly baghouse.

Unit	Operation	Comments
4	Boiler	Firetube below about 15,000 lb steam/hr. Ash content of fuel decides type of firetube on or watertube boiler to be used.
7	Baghouse	Cannot be used on boiler firing oil only; type of ash from solid waste may allow its use.

Costs - Capital - One Time Items (See graph on Page 4.)

Equipment	Thousands of Dollars (1,000 lb of steam) 12	25	130	References	
Equipment cost	103	265	919	T. Devitt, et al., "Population and Characteristics of Industrial/Commercial Boilers in the U.S.," EPA 600/79-79-178a, August 1979.	Costs are for heavy oil boiler; if ash content from solid waste is high, large coal type boiler is required which costs more -- also system for mixing solids oil not included; about 0.1% wt. ash maximum for heavy boiler without special modifications.
Installation	168	224	388		
Engineering	27	49	131		
construction expense	27	49	131		
Construction fees	27	49	131		
Startup	8	13	30		
Contingencies	72	130	346		
Subtotal	432	779	2,076		
Land	3	3	6		
Working capital (fuel excluded)	70	80	151		
Total	505	863	2,233		

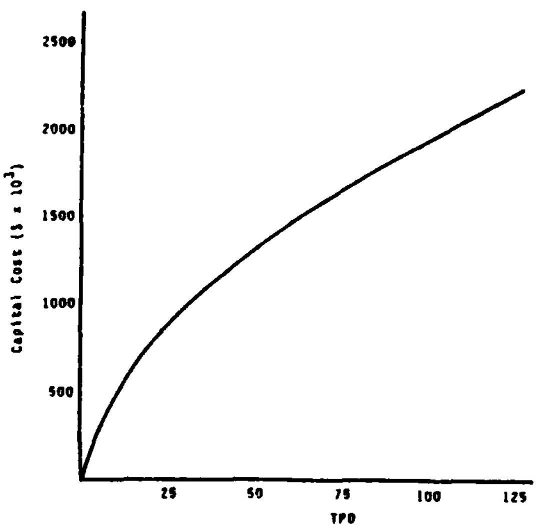
Costs - Recurring (See graph on Page 4.)

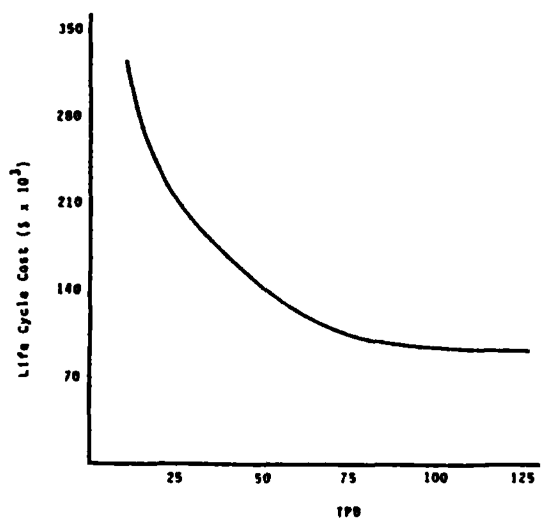
Equipment	Thousands of Dollars (1,000 lb of steam/hr) 12	25	130	References	
Labor and supervision	174	174	335	T. Devitt, et al., "Population and Characteristics of Industrial Boilers in the U.S." EPA 600/7-79-178a, August 1979	
Maintenance	68	75	149		
Electricity	16	35	56		
Steam	17	35	56		
Water	1	1	3		
Chemicals	3	3	7		
Subtotal	279	323	606		
Overhead					
Payroll	52	52	100		Oil/solid mixing system as well as fuel costs are not included.
Plant	63	65	126		
Capital charges G&A, and insurance	17	31	84	(4%)	
Capital recovery	60	109	291	(14%)	
Working capital interest	8	10	18	(12%)	
Total (fuel excluded)	419	590	1,224		

COMBUSTION SYSTEMS	Heavy Fuel Oil/ Solid Slurry	CS-LF-HS	P. 4 of 4

Comments - Notes

The actual boiler used depends on the ash content of the fuel. If the ash content is less than about 0.1 wt. percent, a heavy oil boiler could be used except additional cleaning would be required. If the boiler has a bottom ash removal system and furnace wall soot blowers, up to about 5 percent ash oil/solid slurry may be burned. Some derating may be required. Also, new burners may have to be installed. If oil/solid slurries with larger ash content are to be burned, a coal type boiler will be required. A coal type watertube boiler as compared to an oil-fired unit has a smaller heat release rate or larger furnace for some heat input. Also, the tube spacing in the convection section is greater. System efficiency (80 to 80%) depends if there are economizers or air preheaters.





Note: Fuel costs not included.

PRODUCT MARKETS

Product Characteristics

Product	As Designed	As Experienced	Output Quantity/Ton of Solid Waste
Hot liquids	Not available	Not available	Small
Hot gases	500-600°F	Not available	10-80,000 CFM
Electricity	30-35,000 kW	Not available	Not available
Mechanical power	40-50,000 hp	40-50,000 hp	Not available

Product end uses, specifications

End Use	Average Btu/sq ft/yr (000)	Hot water Gal/sq ft/yr	Steam (lb/sq ft/yr)	Electrical (KWH/sq ft/yr)	Considerations
Offices:	55	336.4	39.5	16.1	ABC (all uses) D,E,G,
Hospital	160	974.0	115.1	46.8	D,E,G
Training Facility	50	304.4	36.0	14.6	D,E,F,H
Housing Family	82	499.2	59.0	24.0	D,E,I
BOO	61	371.3	43.9	17.9	D,E,I
Storage	50	34.4	36.0	14.6	D,E,J
Service	95	578.3	68.3	27.8	D,E,K

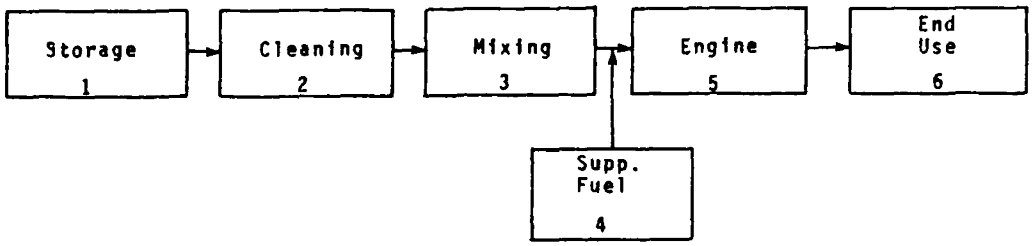
Considerations

A. Budgets listed include a 45% energy reduction as mandated by E.O.12003 for new facilities. Existing facilities for which waste derived energy is being considered will have energy demands exceeding the values listed.
B. Hot water system calculations assumes 20°F temperature drop across radiator. 180°F input. For 30°F drop 2/3 the listed quantity would be required, a 10°F drop would require 2 times the listed quantity.
C. Based on metered rate for electrical energy. Generated rate would require approximately 3.4 times listed figure.
D. Demands listed are heating and cooling loads only. No process energy is supplied.
E. Values listed are heating and cooling loads based on national averages and typical building of this type. Local requirements will vary.
F. Nonworking hour loads will be substantially lower in most cases.
G. Noninterruptable supply is criti al.
H. Demand will fluctuate widely with facility use patterns.
I. Demand will be 24 hour.
J. Cold storage facilities have approximately 2 times the demand as valves listed.
K. Includes laundry/dry cleaning, and commissary facilities.

Recovery Considerations

- Additional fuel costs (90% of the burned fuel).
- Cost of waste oil cleaning systems.
- Cost of additives.
- Availability of engines.
- Duty cycle (required operation).
- Pollution control (systems much meet EPA regulations.
- Additional storage handling requirements.
- Blending compatability.

APPLICABLE TECHNOLOGY



Unit Operations

Number	Function	Typical Equipment	Reference
1	Storage	Tank	Not included
2	Cleaning	Purifier, strainer, filter, separator, etc.	Not included
3	Mixing	Pump	Not included
4	Supplemental fuel	Diesel fuel, gasoline	N/A
5	Engine		CE-I
6	End use		N/A

System Alternatives

Operation	Description	Reference
Treatment	Waste oil is strained, particulate is removed allowing more to be burned	N/A
Precombustion chamber	Adds to the flexibility of the engine	N/A

Unit	Operations	Comments
2	Cleaning	Minimizes adverse effects on engine, increases suitability for burning.
3	Mixing	In-line blender to emulsify waste oil in the fuel.

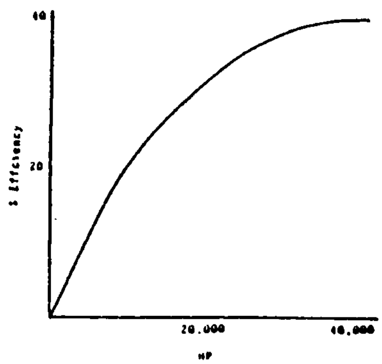
Costs - Capital - One Time Items

Equipment	10	40	Comments
Pretreatment	$140K	$560K	Precise costing information unavailable
Low level	180K	720K	
High level			
Emission control	310K	124K	
Filtration system	15K	60K	

Costs - Recurring

Equipment	10	TPD 1980 $/day 20	30	40
Supplementary fuel	$25K	$50K	$75K	$100K
Maintenance				
Pretreatment				
Low level	408	818	1,227	1,636
High level	425	850	1,276	1,701
Emission control				
Precipitators	82	165	247	329
Filtration	411	823	1,235	1,646
Scrubbers	494	988	1,481	1,975

Btu content: Waste oil Btu content = 12,500 to 20,000 Btu/lb.



COMPLEMENTARY SYSTEMS

- Spectrograph lube oil analysis.
- Fuel metering system.
- Fuel treatment system.

Effects

- Indicates nature of treatment desired.
- Automatically adjusts waste influent to fuel stream.

Comments, Notes

IC engines are not very fuel flexible. Waste oil could be mixed if treatment facilities were available. Can burn 1% without degradation of components or emissions. Waste oil is high in non-removable trace metals.

REFERENCES

1. "Waste Oil Burn-Off in Coast Guard Power Plants," U.S. DOE, 1976.
2. Obert, E. F., Internal Combustion Engines and Air Pollution, Harper and Row, 1973.
3. "Waste Automotive Lubricating Oil Reuse as a Fuel," EPA 600/5-74-032.

AD-A120 639 RESOURCE RECOVERY TECHNOLOGY APPLICATION DOCUMENT(U) 2/3
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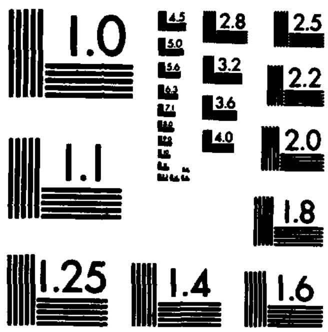


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

COMBUSTION SYSTEMS	Low Btu/Natural Gas Mix	CS-GF-LB	P. 2 of 3

Costs - Capital - One Time Items (4th Quarter 1980) Option 1 (See graph on Page IV-37).

Equipment and Cost Factors	20	30	50
Building, foundation and concrete	24.1	33.4	50.3
Site preparation	3.6	4.9	7.5
Boiler, burner, F.D. fan and stack	150.1	207.7	312.6*
Pumps	1.3	1.8	2.7
Water treatment	1.0	1.4	2.1
Boiler control panel	3.3	4.6	6.9
Pollution control	19.5	27.0	40.7
Construction and supervision	16.4	22.4	33.7
Utilities instalation	13.9	19.2	28.9
Engineering	23.9	33.3	49.9
Total plant facilities investment (PFI)	257.1	355.7	535.3
Organization and startup (5%)	12.9	17.8	26.8
Interest and depreciation of equipment	Omitted		
Total	270.0	373.5	562.1

Costs - Recurring (See graph on Page 3.)

Equipment (Boiler System Only)	TPD ($ x 10^3) 1980 $ 20	30	50
Labor	90.1	90.1	90.1
Electricity	3.5	5.3	8.8
Water	1.8	3.2	5.0
Oil (truck & startup)	6.8	10.3	17.2
Chemical water treatment	1.6	3.8	5.2
Maintenance supplies	5.2	7.1	10.7
Maintenance labor	5.2	7.1	10.7
Admin. overhead	13.5	13.5	13.5
Total	127.7	140.4	161.2
Operating cost $/ton	6.38	4.67	3.22

Comments

Basis for Costs

Labor: 2 men/1st shift + 1 man/2nd shift - 16 hr/day.

Fuel: $4.5/$10^6$ Btu, 75% utilization 16 hr/day, at 4.1 x 10^6 Btu/T.

Water: 100% makeup + 10% blow down @ $0.60/1,000 gal.

Electricity: 1 kW/TPD and $0.04/kWh.

Maintenance: Supplies 2% of capital cost.

Admin. overhead: 15% of operating labor.

Maintenance: Labor 2% of PFI.

COMBUSTION SYSTEMS	Low Btu/Natural Gas Mix	CS-GF-LB	P. 3 of 3

COMPLEMENTARY SYSTEMS

Low Btu Gas Plus Natural Gas as Fuel

A single burner is capable of burning both the LBG and Natural gas. Thus, the capital cost for Option #2 is approximately the same as for Option #1. The piping and control elements for natural gas line hook-up to the burner is negligible compared to the overall project cost. The operating cost will increase by the amount of natural gas used per year. Assuming $3.50 per million Btu of natural gas, the annual cost of natural gas will be $17,323 for 50 TPD, $10,424 for 30 TPD, and $6,899 for 20 TPD.

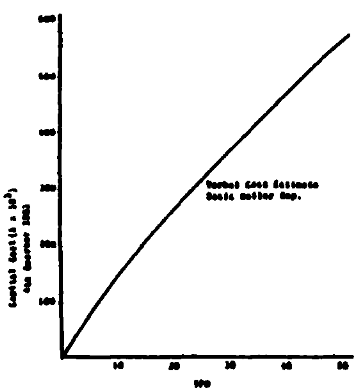
Comments, Notes

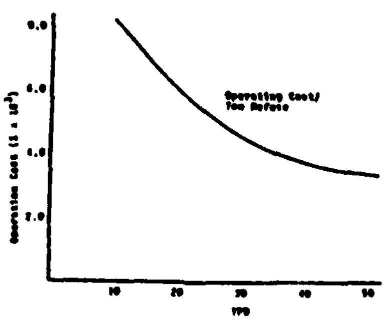
Air gasification of solid waste could produce low Btu fuel gas having up to 80% of the heating value of the solid waste gasified.

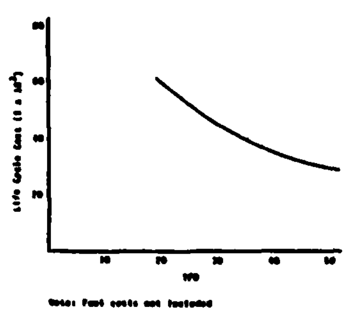
MSW contains an average of 9×10^6 Btu. Therefore, heating value of the low Btu gas = 7.2×10^6 Btu having specific fuel heating value of gas 150-200 Btu/ft^3. This sort of gas can burn without the help of any auxiliary fuel. Boilers designed to burn only low Btu gas will have different combustion chamber volume than for natural gas-burning boilers.

REFERENCES

1. "Thermal Processing of Municipal Solid Waste for Resource and Energy Recovery," by Weinstein and Toro.
2. Personal Communication with Basic Environmental Eng. (verbal quotation).
3. "Small Modular Incinerator Systems with Heat Recovery," EPA No. SW117C, November 1979.
4. "Power Plant E[illegible]g. and Design," by H. Morse, McGraw-Hill.
5. "Mission Analysis for the Federal Fuels from Biomass Program," SRI International, Vol. IV, 1979. Final Report DOE.







COMBUSTION SYSTEM	High Btu Gas/ Natural Gas Mix	CS-GF-HB	P. 1 OF 4

PRODUCT MARKETS

Product Characteristics

Product	Range of Characteristics: As Designed	As Experienced	Output Quantity/Ton of Solid Waste
Hot water	150-300°F at 1-5 atm	150-250°F at 1-3 atm	360 gpm at 30°F temperature difference.
Steam	150-250 psig	150-200 psig	5,400 lb/hr
Electricity			560 kW

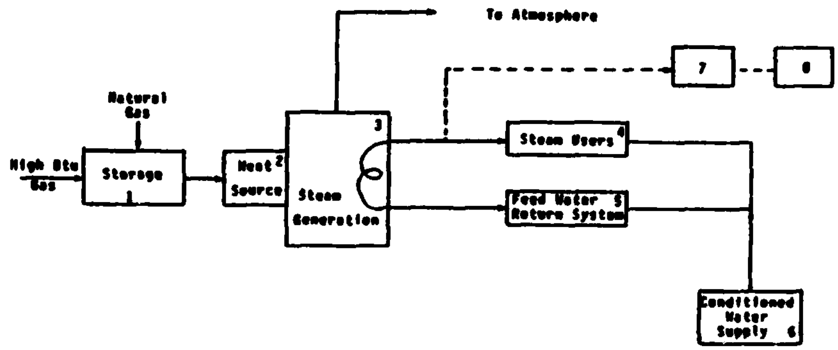
Product end uses, specifications

End Use	Average Btu/sq ft/yr (000)	Hot water Gal/sq ft/yr	Steam (lb/sq ft/yr)	Electrical (KWH/sq ft/yr)	Considerations
Offices:	55	336.4	39.5	16.1	ABC (all uses) D,E,G,
Hospital	160	974.0	115.1	46.8	D,E,G
Training Facility	50	304.4	36.0	14.6	D,E,F,H
Housing Family	82	499.2	59.0	24.0	D,E,I
BOQ	61	371.3	43.9	17.9	D,E,I
Storage	50	34.4	36.0	14.6	D,E,J
Service	95	578.3	68.3	27.8	D,E,K

Considerations

A. Budgets listed include a 45% energy reduction as mandated by E.O.12003 for new facilities. Existing facilities for which waste derived energy is being considered will have energy demands exceeding the values listed.
B. Hot water system calculations assumes 20°F temperature drop across radiator. 180°F input. For 30°F drop 2/3 the listed quantity would be required, a 10°F drop would require 2 times the listed quantity.
C. Based on metered rate for electrical energy. Generated rate would require approximately 3.4 times listed figure.
D. Demands listed are heating and cooling loads only. No process energy is supplied.
E. Values listed are heating and cooling loads based on national averages and typical building of this type. Local requirements will vary.
F. Nonworking hour loads will be substantially lower in most cases.
G. Noninterruptable supply is critical.
H. Demand will fluctuate widely with facility use patterns.
I. Demand will be 24 hour.
J. Cold storage facilities have approximately 2 times the demand as valves listed.
K. Includes laundry/dry cleaning, and commissary facilities.

APPLICABLE TECHNOLOGY

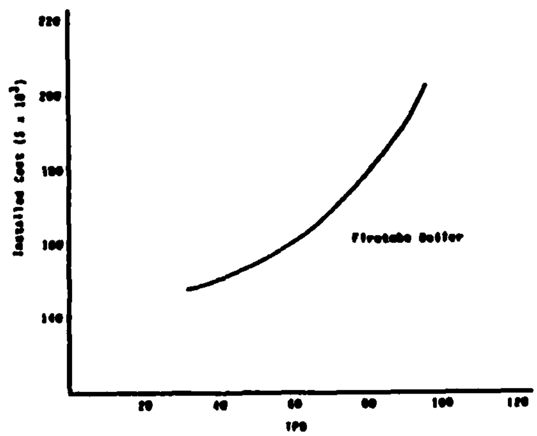


Unit Operations

Number	Function	Typical Equipment	Option #1
1	Storage	Compressed high Btu gas storage tank	Generate steam use steam for building heating and process work
2	Heat source	High Btu gas burner (cell type)	
3	Steam generation	Boiler fired with high Btu gas	
4	Steam users	Building, barracks and others	
5	Feed water return system	Feed water supply systems, pumps, etc.	
6	Conditioned water supply	Make up water supply system	

System Alternatives

Option	Operation	Description
1	Power generation	Steam turbine (non-condensing)
2	Electrical generation	Steam-turbine driven generator



COMBUSTION SYSTEM	High Btu Gas/ Natural Gas Mix	CS-GF-HB	P. 3 OF 4

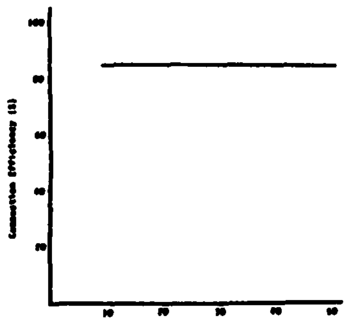
Costs - Capital - One Time Items (4th Quarter 1980) Option #1

Equipment & Cost Factors	TPD - ($ x 10^3) 20	30	50	References	
Site Preparation	0.75	1.03	1.55	Verbal Quotation from Cleaver.	The Capital Cost is for firetube boiler with natural gas burner.
Building, Foundation & Concrete	5.05	6.93	10.43		
Boiler, F.D. Fan & Stack	35.44	48.66	73.23	Brooks Boiler Representative.	
Pumps, etc.	0.27	0.37	0.55	Installation and delivery factor of 3 used in computing total installation costs.	
Control Treatment	0.21	0.29	1.44		
Pollution Control	0	0	0		
Construction	3.38	4.64	7.00		
Utilities Construction	2.90	3.98	6.00		
Engineering	5.00	6.86	10.32		
Total Plant Facilities Investment	53.7	73.73	110.95		
Organization & Startup (5%)	2.7	3.70	5.54		
Total Capital Investment	56.4	77.43	116.49		

Costs - Recurring - (Operating per year)

System Efficiency

Equipment Boiler Systems Only	20	30	50	References
Labor	62.4	62.4	62.4	In most cases 1 man/shift is quite adequate for 2 shift operation. Three men has been taken into consideration. FUEL COST NOT INCLUDED.
Electricity	3.5	6.4	8.8	
Water	1.8	3.2	5.0	
Oil (Trucks and Startup)	5.2	7.5	15.3	
Chemical (water treatment	1.6	3.8	5.2	
Maintenance Supplies	1.1	1.5	2.2	
Maintenance Labor	1.1	1.5	2.2	
Admin. Overhead	9.4	9.4	9.4	
Total Operating Cost	86.1	94.6	110.5	
$/ton	4.31	3.15	2.21	



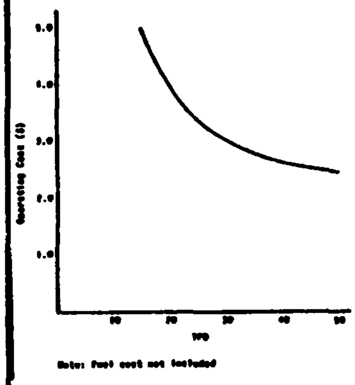
Basis

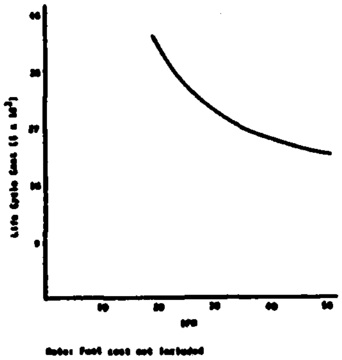
Labor: 2 men/1st shift + 1 man/2 shift - 16 hr/day

Fuel: $4,5/$10^6$ Btu 75% utilization - 16 hr/day at 4.1 x 10^6 Btu/ton.

Water: 100% makeup + 10% B.D. $0.60/1000 gal

COMBUSTION SYSTEM	High Btu Gas/ Natural Gas Mix	CS-GF-HB	P. 4 OF 4





Elec.: 1 kW/tpd and $0.04/kWh

Maint. Supply: 2% of capital cost.

Admin. Overhead: 15% of operating labor.

Maint. Labor: 2% of PFI.

COMPLEMENTARY SYSTEMS AND THEIR IMPACT

High-Btu gas (refuse derived) is equivalent in energy content to natural gas. High pressure steam can be generated to drive steam turbine and generate electricity. The size of the refuse plant is too small for a water tube boiler system. The steam turbine-driven generator, completely installed may cost an additional $50,000. Operating cost will not change significantly.

Comments

Conversion of solid waste to high-Btu gas has not been demonstrated in public sector projects. It involves performing oxygen gasification to produce medium-Btu gas (MBG). The MBG composition will consist of 20 to 25% hydrogen, 35 to 42% carbon monoxide, and 4.5 to 5.8% methane by volume. In order to perform the methanation process and to produce high Btu gas, the initial gas composition should have a H_2 to CO ratio of approximately 3:1.

As the ratio is not present with the initial gas, the MBG has to undergo watergas shift conversion as seen from the relation:

$$H_2O + CO \longrightarrow H_2 + CO_2$$

Then the gas must undergo catalytic methanation process involving reactions as:

$$3H_2 + CO \longrightarrow CH_4 + H_2O$$

The methane-rich gas leaving the combined shift/methanation reactor is then sent to a polish methanation process to reduce the CO level to pipeline gas specifications. CO_2 is removed in bulk by a hot potassium carbonate system and dry SNG is produced. For a small plant of 20 to 50 TPD such an involved process is very seldom recommended. The conversion efficiency ranges from 60 to 63%. In this calculation, it is assumed that an estimated 5.4 million Btu will be realized per ton of refuse processed.

COMBUSTION SYSTEMS	Gas Turbines	CS-GF-GT	P. 1 of 4

PRODUCT MARKETS

Product Characteristics

Product	Range of Characteristics: As Designed	As Experienced	Output Quantity/Ton of Liquid Waste
Compressed air	1-10 atm	Same	Not applicable
Hot gases	500-1,100°F	Same	16,000-500,000 CFM
Electricity	75-75,000 kW	Same	Not applicable

Product end uses, specifications

End Use	Average Btu/sq ft/yr (000)	Hot water Gal/sq ft/yr	Steam (lb/sq ft/yr)	Electrical (KWH/sq ft/yr)	Considerations
Offices:	55	336.4	39.5	16.1	ABC (all uses) D,E,G,
Hospital	160	974.0	115.1	46.8	D,E,G
Training Facility	50	304.4	36.0	14.6	D,E,F,H
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Considerations

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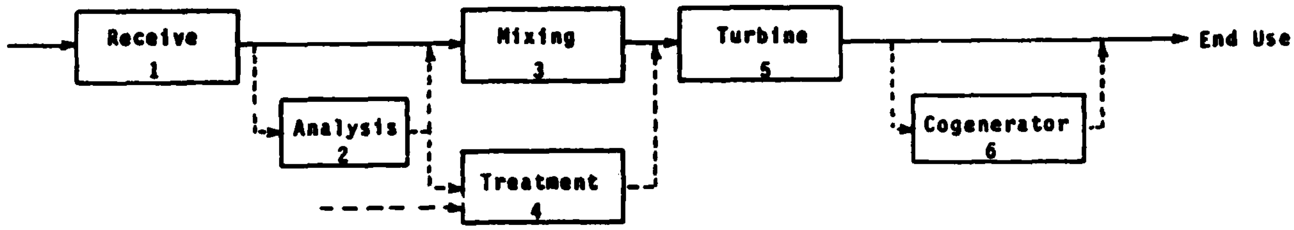
H. Demand will fluctuate widely with facility use patterns.
I. Demand will be 24 hour.
J. Cold storage facilities have approximately 2 times the demand as valves listed.
K. Includes laundry/dry cleaning, and commissary facilities.

APPLICABLE TECHNOLOGY



Unit Operations

Number	Function	Typical Equipment	Reference No.
1	Receive	Storage tank	Not included
2	Analysis		Not included
3	Mixing	Pumps, mixers	Not included
4	Treatment	Purifiers, filters, coalescers	Not included
5	Turbine	Direct or indirect-fired combustor	CE-F
6	Cogenerator	Waste heat boiler	CE-G

System Alternatives

Operation	Description	Reference No.
Atomization	Dual orifice injection, allowing waste oil to be supplied when available.	Not included
Treatment	Purifiers and filters or additives, additives usually have to be approved by manufacturer.	Not included
Combustor	Designs are being modified to handle increased flexibility in fuels.	Not included

Unit	Operations	Comments
2	Analysis	Analysis is important as it determines the amount to be used, the treatment required.
3	Mixing	May be an alternative to analysis and treatment.
4	Treatment	Effects system life, usually pays for itself by reduced (normal) fuel costs.
6	Combustion Cogeneration	Closely monitored for direct fire applications. Improves cycle efficiency up to 20%. (See graph on Page 4.)

Costs - Capital - One Time Items

Equipment	Tpd (# x 10^3) 10	20	30	40	Comments
Turbines (60-240 $/hp)	960K -3760K	1.92M -7.52M	2.86M -10.28M	3.84M -15.04M	Precise costing information not available at this time
Water treatment for NO_x control	8-25K ($1.5/kW)			100K -170K	

Costs - Recurring

Equipment	Tpd 1980 10	20	30	40
Increased maintenance		Data not available		
Filter replacement		Data not available		
Supplementary fuel	$25K/day	$50K/day	$75K/day	$100K/day $7.3K/yr

Btu Content: Waste oil Btu content = 12,500 to 20,000 Btu/lb

COMPLIMENTARY SYSTEMS

Fuels treatment - fuel treatment costs are dependent on fuel properties. Analysis of the waste oil to be burned should be performed for assessment of treatment cost.

- Filtering.
- Separation.
- Additions.
- Dual injection nozzles.

Effects

- Filtering removes large particulates. decreases wear in engines, and may allow more waste oil to be burned as a result.
- Separation removes water and particulates, increases performance, and will increase amount of waste oil that can be mixed.
- Additives ease mixing, upgrade performance, reduce wear, corrosion of hot gas parts.
- Dual injection nozzles increase amount of (cleaned) waste oil that can be used.

Comments - Notes

Any use of waste oil should probably be in existing machinery as new equipment is expensive. New equipment should be purchased with its ability to burn waste products in mind, when viewing alternatives.

REFERENCES

1. Byam, J. W., "Residual Fuel Treating and Handling for Base Load Gas Turbines," ASME Paper 75 GT 72.
2. Krulls, G. E., "Gas Turbine Liquid Fuel Treatment and Analysis," ASME Paper 74-GT-44.
3. Hobbs, J. R., "Waste Oil Burn Off in Coast Guard Power Plants," U.S. DOT, 1976.
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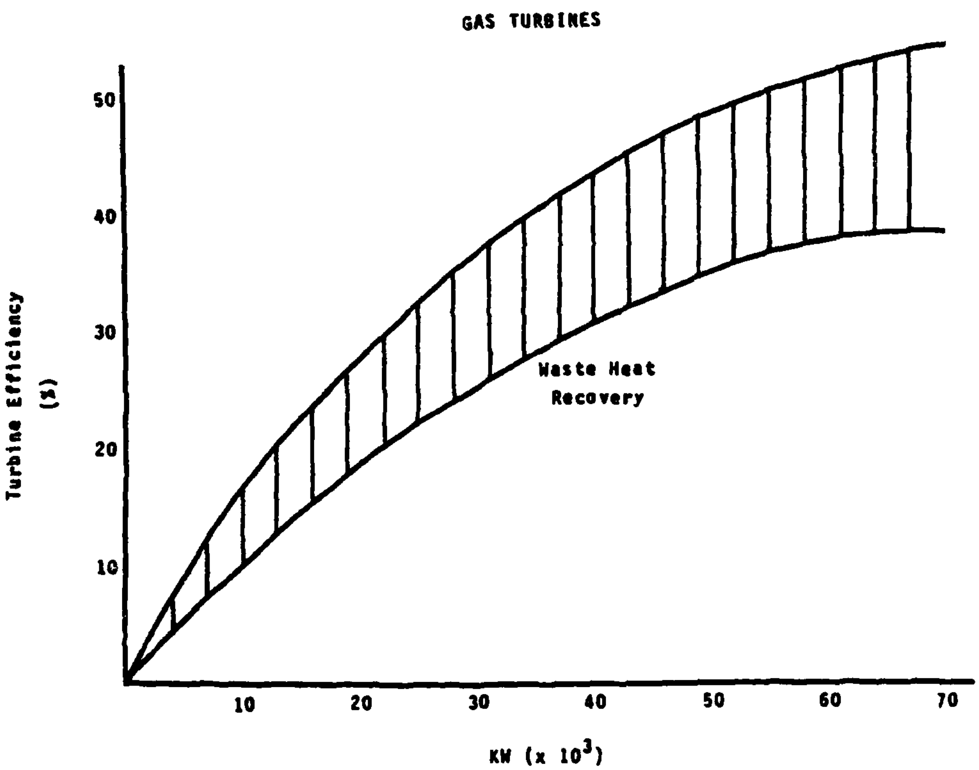

SECTION V

INSTITUTIONAL CONSIDERATIONS FOR NAVY RESOURCE RECOVERY PROJECTS

Technology selection, which is the primary focus of this document, has in recent years proved to be only one of several important facets of a successful project. Industry experts no longer measure the success of a project solely by how well the system works, but also carefully monitor the financial health of the project as well as the success of the contracting mechanism used to procure the project. Federal and state environmental officials are also keeping a close watch on the facility air emissions, liquid effluents, and residue characteristics in an effort to develop formal policies on their proper management.

The following is a summary description of several of the more important institutional considerations in resource recovery implementation. Because most of the energy recovery experience has taken place on the municipal level, practical guidance for implementing a resource recovery project would logically come from the municipal experience. Anyone considering the implementation of a resource recovery project should closely study municipal resource recovery projects in order to gain a better understanding of the implementation process.

PLANNING AND SCHEDULING

The first step in the development of a resource recovery project is an analysis of its feasibility at a given installation. It is important to recognize that the data base developed for a feasibility study is typically inadequate for proper planning and implementation. Several municipalities have made this mistake, and their projects are technical or financial failures as a result.

Typical elements of a proper resource recovery planning and scheduling analysis include an analysis of waste quantity and composition, including laboratory analysis for fuel characteristics; a formal solid waste management plan, which fully describes the refuse collection and disposal strategy for 10 to 20 years; a complete assessment of landfill life and adequacy of current landfill operation, as any resource recovery project requires that landfill capacity be available for residues and overflow; an assessment of waste availability to the resource recovery project; and an analysis of how source separation/recycling can be integrated into the overall resource recovery program. Detailed analysis of these aspects of solid waste management may produce some conflicts or discrepancies with the previous resource recovery feasibility study. Changes to the feasibility study should therefore be made to reflect these differences and to assess the resulting impact on the previous decision.

ENERGY AND MATERIAL MARKETS

Many experts consider market studies and negotiations to be the most important aspects of a successful resource recovery project. Market studies for energy play a more significant role in municipal projects, as most of these projects sell the product to a utility or other industry. A Navy-scale energy recovery project will ordinarily use the steam or electric power product on base. The development of proper specifications and demand profiles for these products to ensure a reliable on-base market is a key factor in Navy resource recovery assessment.

The sale of recovered material is in many ways simpler than for energy products. Source separation activities throughout the country have paved the way for the use of recovered material as secondary material in industry. The consuming industries are familiar with the quality of materials recovered through both source separation and mechanical separation. ASTM has developed standards for most of the commonly recovered materials in resource recovery, which further aid planning and market contracts development for such projects. In addition, DOD and the Navy have established policies promoting material recovery at military installations, and standard procedures exist for the sale of recovered materials through the Defense Property Disposal Office (DPDO).

In most instances, mechanical separation of materials such as ferrous metal and aluminum results in a higher volume and poorer product quality than source separation. Discussion of market potential and contracts should be initiated through DPDO with major consuming industries or major brokers, rather than local recycling organizations which are accustomed to handling a cleaner, low-volume product. Several of the references listed at the end of this section will aid in identifying some of the major local secondary material industries.

PROJECT FINANCING

Most Navy-scale projects for material or energy recovery will cost less than $10 million (1981); as such, they will not usually require any special form of financing. Most Navy public works projects of this type are financed through capital budget allocation, the DD 1391 process. Most municipal projects, on the other hand, are financed through revenue bonds, in which the economic viability of the project is paramount. Case histories of revenue bond financing on the municipal level are readily available through EPA research reports and through other cognizant agencies such as the U.S. Conference of Mayors. Navy personnel must be well acquainted with revenue bond financing, as it is critical to involvement in a regional resource recovery project.

RISK ANALYSIS AND PROCUREMENT

There are three procurement strategies which are commonly used for resource recovery projects:

- Architect/Engineer - An A&E firm designs and constructs a resource recovery plant, the technology for which is specified and selected by the client.

- Turnkey Contract - A vendor or A&E consortium designs, constructs, and starts up a recovery plant. The plant is turned over to the client once the predetermined performance specifications have been met.

- Full-Service Contract - A vendor designs, constructs, starts up, and operates a facility for a client, in essence providing a resource recovery service for a contracted tipping fee and possible operating subsidy. The contractor may also hold an equity position in the project.

The selection of a particular procurement strategy is necessarily a function of the amount of risk that the implementing agency is willing to take on the project. Shedding part of the risk by employing a full-service contractor, for example, will typically reduce the Navy's risk in exchange for a higher disposal cost.

The most common risks encountered in resource recovery planning relate to waste stream quantity and composition, facility construction and operation, by-product marketing, and waste disposal/environmental impact. Waste flow control guarantees, a common problem in municipal resource recovery, should not be of concern at most Navy facilities. However, the risk associated with waste quantity and composition is increased if proper measurement techniques are not used in advance of the design phase.

Problems associated with facility construction and operation are numerous, and may include cost overruns during construction, unreliable system performance, or improper operation of the facility. These latter reasons are the primary impetus for increased use of turnkey and full-service contractor procurement among municipalities. The inability of a system to meet its by-product specifications is more prevalent among municipal systems, because the by-product is being sold under contract to industry. In Navy operations, poor performance of this type may still present a problem by impeding the desired public works mission (e.g., steam supply reliability, electric power reliability).

The last area of risk listed above, disposal/environmental impact, may be the most important risk to be considered. Resource recovery plants may be implemented in an effort to lengthen existing base landfill life. Unreliable plant operation results in increased landfill requirements, and would therefore defeat the purpose of these projects. Similarly, improper operation of an energy recovery plant may result in unacceptable air emission levels, thereby replacing perceived long-term environmental impacts from land disposal with an observable problem with air emissions.

Each of the risks listed above is inherent to a resource recovery project. Among the resource recovery projects in our major cities, these risks have been distributed in a variety of fashions. The key to proper risk management is selection of the appropriate procurement strategy, coupled with proper project planning and organization at the facility level.

USE OF OUTSIDE ASSISTANCE

Use of outside engineers to assist in public works project design has been an accepted practice among the military. Implementation of resource

recovery projects brings several added dimensions to the traditional project implementation approach, as it requires expertise in new technology areas. Areas in which resource recovery assistance from an outside engineering firm may be valuable include solid waste management planning, technology selection, and environmental impact assessment. These disciplines go beyond traditional architect/engineer capabilities, and may require a separate procurement for each area in order to obtain the appropriate range of capabilities. Expertise in each of these areas is available from specialty firms throughout the United States. Municipal resource recovery projects have also enlisted assistance from experts in other peripheral areas such as risk assessment, market identification and contract negotiation, and overall project management. Lists of consultants and engineers in each of the specialty areas can be obtained from cognizant federal agencies as well as cities that have already implemented resource recovery projects.

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APPENDIX A

MATERIALS HANDLING EQUIPMENT (MH)

COMPONENT DESCRIPTION

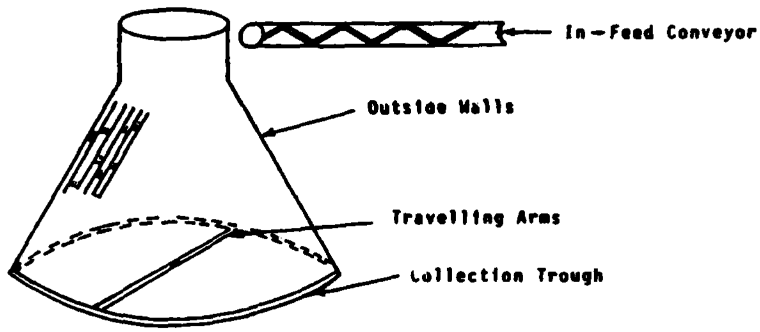
Storage Silo

Type
Live Bottom

Types Available - Competing Components
a. Live bottom

Types Used Commercially
a

Physical Characteristics



General Description

Patterned after silos in use for wood chip/sawdust storage. Silos may be as large as 150 ft in diameter and 80 ft high. Diameter increases toward bottom.

Principle of Operation

Material is fed from above, and removed from underneath. The continuous revolving arms at the bottom of the unit impart a constant downward motion to prevent bridging and freezing.

Materials of Construction

- Walls; wood - concrete.
- Floor - reinforced concrete.
- Traveling arms - steel.

Advantages Over Other Types

- Elimination of bridging.

SIZING CRITERIA

Daily throughput rates usually designed to store 3 to 5 days of RDF volume to allow downtime surge capacity.

ACCESSORY COMPONENTS

- Input/output conveyors (belt or pneumatic).

SUPPORT REQUIREMENTS

Personnel: Maintenance only, 1/4 man day per day.

Training: General maintenance, motor repair, welding.

Skills Required: Welding, motor repair, concrete.

Inspections: Frequent; high moisture content encourages bridging.

Access: Sufficient for inspection, maintenance.

Spare Parts: Traveling arms.

Permits: None required.

OPERATIONAL CONSIDERATIONS

General: First material in - first material out.

Installation: Locate to minimize conveyor reach.

Maintenance: Traveling arm/floor wear; traveling arm motor.

Controls: Traveling arm speed; input conveyor speed.

Scheduling: Based on manufacturer's recommendations.

Downtime: Can require entire system to shut down if redundancy doesn't exist.

STATE-OF-THE-ART

R&D Needs: Storage time as a function of moisture content and other compositional values.

Operating Systems: Ontario, Canada; Baltimore, Maryland, and Iowa.

Risks: Bridging, or other bin flow problems will cause flow failures.

Failures: Baltimore, Maryland; bridging resulted in over spec traveling arm motion causing premature equipment wear.

COMPONENT DESCRIPTION

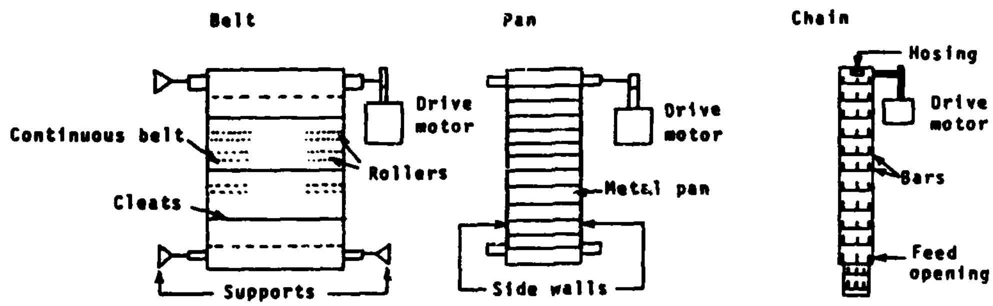
Conveyors

Type
Continuous

Types Available - Competing Components
a. Belt
b. Pan
c. Chain

Types Used Commercially
a, b, c

Physical Characteristics



General Description

Continuous conveyor belts are used to move material between receiving areas and processing equipment, between unit operations within the processing line and from final processing to storage or loading areas. The successful conveyance of materials is critical to any resource recovery system. Most conveyors are available in open or closed configurations.

Principle of Operation

Material to be moved is deposited on the conveyor (or into an enclosed trough in chain types) and is carried by the conveyor as it moves along its prescribed tracks. Route may be inclined, horizontal or vertical (enclosed chain types only). Drive mechanisms typically consist of electrical motors with chain or gear drives.

Materials of Construction

- Pans - AISI 1040 steel or other carbon steel - may be reinforced with structural steel bracing.
- Belts - nylon carcass rubber covering, neoprene cleates.
- Supports - structural steel.

Advantages Over Other Types

Pan type conveyor systems offer greater life expectancy and volume handling capability. Belt type offers low initial costs. Enclosed chain type allows for steeper ascent angles than belt or pan conveyors.

SIZING CRITIERIA

	Capacity (tons/hr)			
	5	10	20	50
	Width of Conveyor (in)			
Belt	6 through 36 available			
Chain type	5	5-9	7-11	9-25
Belt type	12 through 120 or greater available			

ACCESSORY COMPONENTS

- Drive motors.
- Support structures.
- Covers, typically supplied by manufacturer/vendor.

SUPPORT REQUIREMENTS

Personnel: No individual personnel are required to operate conveyors.

Training: Minimal; maintenance training provided by manufacturer/vendor.

Skills Required: Minimum mechanical for maintenance.

Inspections: Routinely for wear, lubrication.

Access: Adequate, at all points for maintenance.

Spare Parts: Data not available.

Permits: None.

OPERATIONAL CONSIDERATIONS

General: Conveyors are typically the emergency stopping mechanism for recovery systems. Therefore, adequate observation and control equipment must be installed.

Controls: Automatic shutoff from failure of another unit operation.

Scheduling: 24 hour operation possible.

Downtime: Minimal provided maintenance is carried out.

Other Factors: Refuse, particularly raw refuse, does not turn corners well. Straight line systems are far superior to ones with turns. Shredded refuse is more willing to turn corners.

SAFETY AND ENVIRONMENTAL CONSIDERATIONS

General: Emergency shutoff of conveyors if a processing operation fails.

Fire Hazard: Minimal, fires developing elsewhere in plant (shredder) may propagate along conveyors. Fire suppression equipment should be available.

Explosion: Minimal.

Other Safety: None.

General Environmental: Dust control measures should be taken.

COST ANALYSIS

Manufacturers will quote prices for specific configurations only.

STATE-OF-THE-ART

R&D Needs: Conveyors are proven in many years of use; ability to turn corners needs work. Wet material conveying.

Operating Systems: Many.

Manufacturers:

- Williams Patent Crusher, MO.
- Mayfram Inc., OH.
- Buhler-Miag, Inc., MN.
- Many others.

Risks: Few.

History: Conveyor systems have been used successfully in the resource recovery field as well as many other applications for many years.

Successes: Heavy duty construction for refuse applications.

Failures: Systems, where conveyor system is inaccessible, have jammed and been difficult to repair.

Key Problems: Wire and cables getting caught up in drive mechanisms, belt life with impact loads as experienced in refuse handling systems.

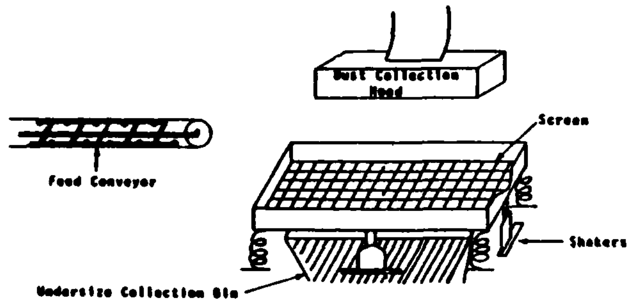
MATERIALS HANDLING	Separation	MH-C	P. 1 of 3

COMPONENT DESCRIPTION

SCREEN Screen	Type Vibrating

Types Available - Competing Components a. Horizontal b. Vertical	Types Used Commercial'y a, b

Physical Characteristics



General Description

Typical units are usually rectangular, with side walls and heavy gauge wire forming the screen. Supported by springs and pneumatically or hydraulically vibrated on top of an undersize collection bin and underneath a dust hood.

Principle of Operation

Waste is deposited at one end of the screen and moved across to the other by directed vibration or gravity (inclined). The material is agitated by the vibration to overcome binding. Undersize material passes thru the screen openings and is collected in a bin. The oversize fraction pass over the screen onto a conveyor.

Materials of Construction

- Screen - heavy gauge wire or expanded metal.
- Other - steel.

Advantages Over Other Types

- Compact.
- Ease of maintenance.

SIZING CRITERIA

- Area - material throughput particle size range.
- Vibrational speed - separation efficiency, material throughput.
- Inclination - material throughput, efficiency.

ACCESSORY COMPONENTS

- Feed and discharge conveyors/collectors.
- Dust collection equipment.

SUPPORT REQUIREMENTS

Personnel: No operator is specifically assigned.

Training: Welding, motor and hydraulic repair.

Skills Required: Maintenance.

Inspections: Stress failures, binding.

Access: Good - no general dismantling required.

Spare Parts: Springs, hydraulic hoses, wire.

Permits: None.

OPERATIONAL CONSIDERATIONS

General: General support base must be rugged.

Installation: Overall equipment balance important.

Maintenance: Heavy; stress loadings high.

Controls: Vibrational (speed) inclination, waste loading.

Scheduling: Due to unpredictable downtime redundancy may be desirable.

Downtime: Excessive and unpredictable.

Other Factors:

SAFETY AND ENVIRONMENTAL CONSIDERATIONS

General: Not particularly hazardous operation.

Fire Hazard: Low - specific preventive measures not usually specified.

Explosion: Low - explosion suppression not usually specified.

Other Safety: Spring supports should be restrained with steel cable in case of failure.

General Environmental: Vacuum dust collection necessary in enclosed applications.

COST ANALUSIS

Cost varies widely based on design and capacity. See manufacturer for quote, particularily custom designs.

STATE-OF-THE-ART

R&D Needs: Optimum opening sizes and spacing.

Manufacturers: Numerous, but not always a stock design or item.

Risks: Without sufficient redundancy, excessive downtime.

History: Extensive use in the rock products industry, not used extensively in solid waste processing except where space is critical.

Key Problems: High-stress factors induced by vibrational motion cause accelerated component failure.

COMPONENT DESCRIPTION

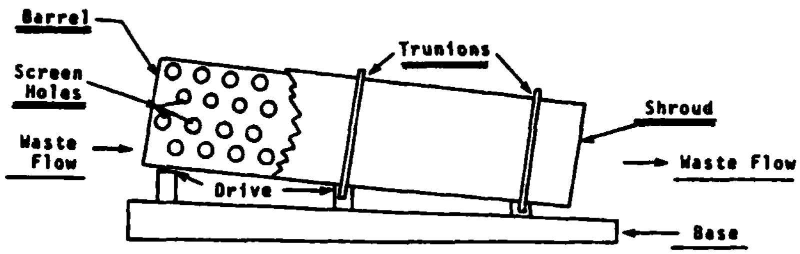
Trommel Screens

Type
Rotary

Types Available
a. Rotary

Types Used Commercially
a

Physical Characteristics



General Description

A cylindrical barrel, perforated with uniform or various size holes covered by a shroud, inclined to the horizontal in the direction of waste flow, rotated by drive trunions, and supported on an integral base.

Principle of Operation

Waste is fed into the higher barrel end. The tumbling action of rotation exposes all material to the circumferential holes. Undersize material passes through the holes into the shroud. Oversize material travels the length of the barrel and is discharged.

Materials of Construction

- Shroud - mild steel.
- Barrel - hardened steel.
- Trunions - hardened steel.
- Drive - rubber-tracked steel wheels.

Advantages Over Other Types

- Low maintenance and operating cost.
- Simplicity of operation.
- High separation efficiency.

SIZING CRITERIA

- Diameter - expected range of particle size and waste throughput.
- Length - desired separation efficiency and material thruput.
- Inclination - material throughput, residence time, and particle size.
- Rotation speed - desired separation efficiency material throughput rate.

ACCESSORY COMPONENTS

- Feed and discharge conveyors.

SUPPORT REQUIREMENTS

Personnel: No special operator is needed.

Training: Motor repair, welding, electrical.

Skills Required: General maintenance; lubrication, motor repair, and general welding.

Inspections: Motor load, blinding of holes, lubrication, barrel trueness, drive wear.

Access: From inside barrel, or outside shroud.

Spare Parts: Rubber drive tracks, motor.

Permits: None.

OPERATIONAL CONSIDERATIONS

General: Match rotational speed with waste throughput rate.

Installation: Barrel trueness must be exact to control separation.

Maintenance: Regular lubrication.

Controls: Angle of inclination and rotational speed - motorload.

Scheduling: Continuous operation possible.

Downtime: Briefly once/week or more frequently to remove entrapped material.

SAFETY AND ENVIRONMENTAL CONSIDERATIONS

General: Motor noise attentuation is necessary, but baffling should be adequate.

Fire Hazard: Low - sprinklers optional, not usually specified.

Explosion: Low - explosion suppression usually not specified.

Other Safety: Guards surrounding trunion drive train.

General Environmental: Dust suppression via venting.

COST ANALYSIS

Each unit is custom designed and built, so only limited capacital cost data is available. (See graphis below.)

STATE-OF-THE-ART

R&D Needs: Optimum hole(s) size.

Operating Systems: New Orleans, LA (Recovery I), Monroe County, NY

Manufacturers: Numerous; shop-fabricated.

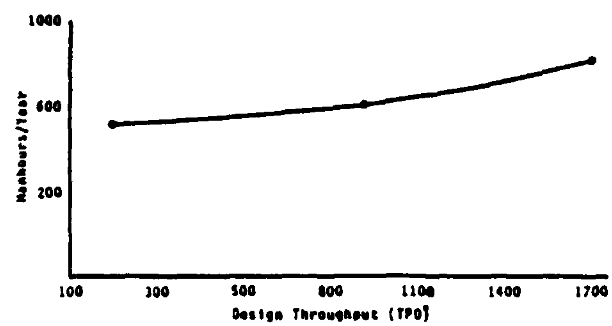
Risks: Low - equipment in service for many years in other industries.

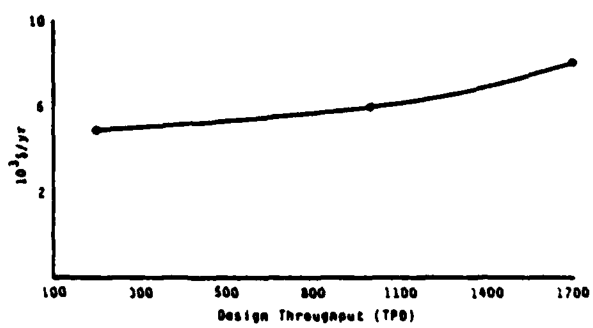
History: Equipment developed primarily in the rock products industry for sizing of crushed ore. Extension into solid waste processing has been generally favorable. Low cost operation gaining in popularity.

Successes: Recovery I in New Orleans most notable. Failures of RDF operations have never been primarily attributable to rotary trommel screen malfunction.

Failures: Collar breakage, barrel out of true, trunion and drive wear, motor overload.

Key Problems: Collar breakage, barrel out of true, trunion and drive wear, motor overload.





COMPONENT DESCRIPTION

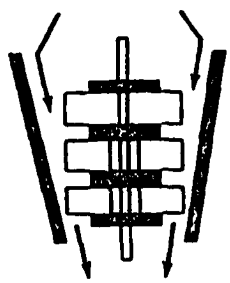
Shredder

Type
Vertical Hammermill

Types available - competing components
a. Vertical hammermill
b. Horizontal hammermill
c. Rotary shear
d. Ball mill
e. Flail mill

Types used commercially
a, b, c,

Physical Characteristics



General Description

Initially shredders were used to prepare refuse for landfilling. It was anticipated that shredded refuse would not require daily cover and that greater compaction densities would be obtainable. Both of these initial objectives are no longer focal points of shredding.

Shredders are generally the initial processing step in a resource recovery facility. The shredded refuse is more homogeneous in nature, particle size is within known limits, and any containers or bags are opened exposing the contents to subsequent processing steps. Shredding also greatly increases the packing density of recovered materials and promotes more complete combustion if incineration is employed.

Principle of Operation

Raw refuse enters a vertical hammermill through a large infeed opening at the top. Rotating hammers, mounted on a vertical rotor shaft, initially contact the refuse, which through impact break apart many items. The refuse continues falling through the unit impacting subsequent hammers which through shearing action reduce the particle size. The conical cross section of the mill further reduces the particle size distribution as the refuse moves downward.

Final reduction takes place below the main hammer section in a straight cylinder section. Here additional hammers force the material against breaker bars or other solid structures built into the shell of the unit. The final product is discharged horizontally through an opening at the side of the unit.

Materials of Construction

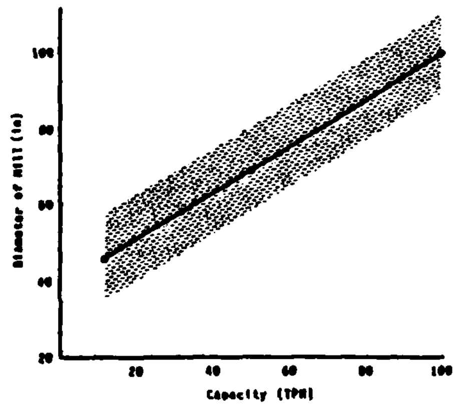
Shell	Hot rolled steel, lined with hot rolled steel or cast manganese attached with countersunk bolts
Hammers	11-14% cast manganese steel, other hardened steel
Rotors	SAE 5155 steel, heat treated

Advantages Over Other Types:

- Horizontal discharge at any position.
- Reduced maintenance costs due to lack of grates.
- Lower overall height.

SIZING CRITERIA

Unit: Vertical hammermills are typically available for between 50-2300 tpd operations.



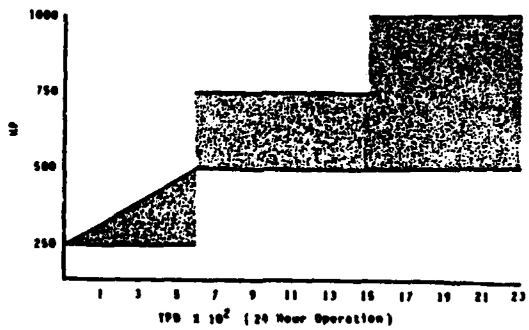
Drive Motor: 250-1,000 hp depending on the throughput, particle size, nature of waste stream, etc.

Opening: 42-92 in, depending on model, throughput, nature of waste stream, etc.

Overall Size: Length 15-18 ft, width 13-20 ft, height 16-22 ft.

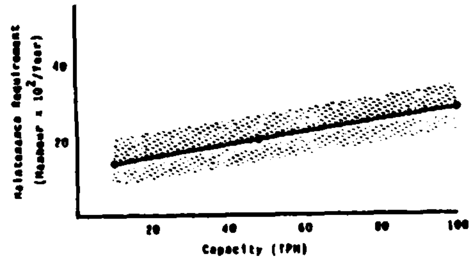
Weight: 15,700-180,000 lb (includes motor, coupling, infeed, and discharge housing)

Size of Motor (typical).



ACCESSORY COMPONENTS

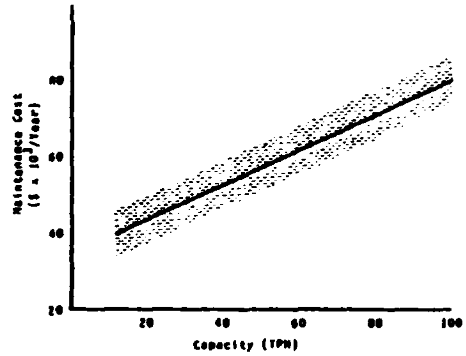
- Feed conveyors
- Discharge conveyors
- Ejected material collection



SUPPORT REQUIREMENTS

Personnel: No additional personnel are needed to operate the hammermill above that required to run a facility. A welder is usually required weekly.

Training: Training is needed to learn maintenance procedures. No additional training is needed. Hammer resurfacing requires welding skills.



Skills Required: No special skills are needed to operate the unit.

Inspection: Hammermills should be routinely inspected for hammer wear, bearing wear, and lubrication.

Access: Adequate access on all sides and top for maintenance.

Spare parts: Replacement hammers, bearing lubricant, bearings, drive gear/belt (if applicable).

Permits: No special permits are required.

OPERATIONAL CONSIDERATIONS

General: Shredders are usually trouble free but high maintenance units. Pre-sorting of unshreddable or hazardous items such as engine blocks, or gasoline cans is recommended.

Installation: No special installation requirements exist. Units are usually delivered fundamentally intact.

Maintenance: Routine maintenance of hammers, bearings, and drive gears is critical to trouble free operation. Hammers require daily inspection and may require weekly resurfacing depending on wear patterns and material. Hammer replacement is necessary when resurfacing is impossible.

Controls: Automatic with manual override.

Scheduling: 24 hr/day operation is possible provided the unit is off-line at least a portion of one day/wk for hammer maintenance.

Downtime: Shredder history is excellent, maintenance is key to limiting down time.

Other Factors: Oversized items need to be removed or reduced in size prior to entering the shredder. Hammermills do not shred tires well.

SAFETY AND ENVIRONMENTAL CONSIDERATIONS

General: Shredders are perhaps the most hazardous single unit operation in a recovery facility.

Fire Hazard: Combustible items entering the shredder or a buildup of dust in the unit can create a fire hazard. Fire suppression equipment should be specified.

Explosion: Explosions in MSW shredders are numerous. The potential exists for explosions to occur within the shredder or along the outfeed conveyors. Internal explosions are usually directed upwards through the infeed opening, while those occuring in the outfeed shoot are directed in all directions. Facility layout and roof design should be specified to reduce potential danger and damage. Explosion suppression equipment should be specified.

Other Safety: Maintenance should be routinely scheduled to avoid unnecessary operator adjustments of online units.

General Environmental: Dust suppression may be necessary. No other emissions are generated.

COST ANALYSIS

Capital cost range: \$50,000-\$750,000 depending on throughput capacity and manufacturer. However, cost is not solely a function of capacity. Reported cost of a 50 TPH shredder ranged from \$75,000-\$750,000 depending on duty. Most hammermills installed in RDF systems are 40 to 70 ton/hour capacity, and cost from \$450,000 to \$600,000.

Life Cycle Analysis

High levels of maintenance and energy costs are associated with all shredders. Expected life-span of units is 15-20 years provided adequate maintenance is provided.

STATE-OF-THE-ART

R&D Needs: Shredders have a good overall operating history. Research needs to be done to reduce maintenance requirements and determines the effect of design characteristics on energy requirements, throughput and particle size distribution. Explosion prevention and suppression will always be a problem without waste sorting.

Operating Systems: Greater than 32 operating systems throughout the U.S. and Canada.

Manufacturers:

- The Heil Company.
- Hammermills, Inc.
- Jeffrey Manufacturing
- American Pulverizer

Risks: Proven explosion prevention devices do not exist.

Other Information: None (Problem materials)

History: Shredders have been in use for many years in the scrap auto processing industry. Their introduction into MSW processing occured in the 1950's. Interest in shredders increased in the 1960's when it was felt that shredding could eliminate the need for daily cover of landfilled waste. The rise of RDF production in the 1970's dramatically increased the use of shredders.

Successes: Shredders have proven themselves in many thousands of hours of operation.

Failures: No major failures have been reported.

Key Problems: Numerous explosions and high maintenance costs.

References:

COMPONENT DESCRIPTION

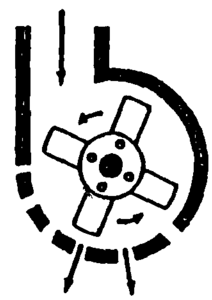
SHREDDER
Shredder

Type
Horizontal Hammermill

Types Available - Competing Components
a. Vertical hammermill
b. Horizontal hammermill
c. Rotary shear
d. Ball mill
e. Flail mill

Types Used Commercially
a,b,c

Physical Characteristics



General Description

Initially shredders were used to prepare refuse for landfilling. It was anticipated that shredded refuse would not require daily cover and that greater compaction densities would be obtainable. Both of these initial objectives are no longer focal points of shredding.

Shredders are generally the initial processing step in a resource recovery facility. The shredded refuse is more homogeneous in nature, particle size is within known limits, and any containers or bags are opened exposing the contents to subsequent processing steps. Shredding also greatly increases the packing density of recovered materials and promotes more complete combustion if incineration is employed.

Principal of Operation

The rotor shaft is mounted in a horizontal position with bearings at both ends. Hammers are free swinging. Waste is fed through the top of the unit and descends by gravity. Stationary breaker bars and a curved grate line the lower portion of the mill. The breaker bars serve as the surface of distruction for large items. The small spacing between the grate and the hammers at their greatest extension serves to continually reduce particle size until the particle is smaller than the opening in the grate. Particle size is therefore determined by the size of the grate openings.

Materials of Construction

Shell	Hot-rolled steel, lined with hot-rolled steel or cast manganese attached with countersunk bolts
Hammers	11-14% cast manganese steel, other hardened steel
Rotors	SAE 5155 steel, heat treated

Advantages over other types:

- Accessability for inspection and maintenance.
- Particle size consistency.

SIZING CRITERIA

Unit: Horizontal hammermills are typically available for between 50-2,300 tpd operation.

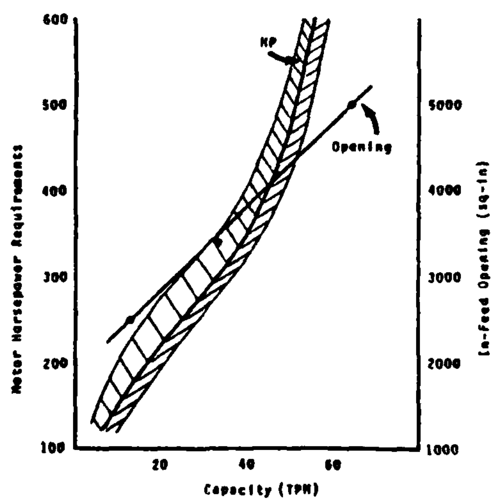
Drive Motor: 250-1,000 hp depending on throughput, particle size, nature of waste stream, etc.

Opening: 42-92 in, depending on model, throughput, nature of waste stream, etc.

Overall Size: Length 15-18 ft, width 13-20 ft, height 16-22 ft

Weight: 15,700-180,000 lb (includes motor, coupling, infeed, and discharge housings)

Size of Motor (typical):



ACCESSORY COMPONENTS

- Feed conveyors.
- Discharge conveyors.
- Ejected material collection.
- Explosion suppression.

SUPPORT REQUIREMENTS

Personnel: No additional personnel are needed to operate the hammermill above that required to run a faciliTY. A welder is usually required weekly.

Training: Training is needed to learn maintenance procedures. No additional training is needed. Hammer resurfacing requires welding skills.

Skills Required: No special skills are needed to operate the unit. Resurfacing hammers requires welding skills plus moderate mechanical skill.

Inspection: Hammermills should be routinely inspected for hammer wear, bearing wear, and lubrication.

Adequate access on all sides and top for maintenance.

Spare Parts: Replacement hammers, bearing lubricant, bearings, drive gear/belt (if applicable)

Permits: No special permits are required.

OPERATIONAL CONSIDERATIONS

General: Pre-sorting of unshreddable or hazardous items such as engine blocks or gasoline cans is recommended.

Installation: No special installation requirements exist. Units are usually delivered fundamentally intact.

Maintenance: Routine maintenance of hammers, bearings, and drive gears is critical to trouble free operation. Hammers require daily inspection and may require weekly resurfacing depending on wear patterns and material. Hammer replacement is necessary when resurfacing is impossible.

Controls: Automatic with manual override.

Scheduling: 24 hr/day operation is possible provided the unit is off-line at least a portion of one day per week for hammer maintenance.

Downtime: Shredder history is excellent, maintenance is the key to limiting down-time.

Other Factors: Oversized items need to be removed or reduced in size prior to entering the shredder. Hammermills do not shred tires well.

SAFETY AND ENVIRONMENTAL CONSIDERATIONS

General: Shredders are perhaps the most hazardous single unit operation in a recovery facility.

Fire Hazard: Combustible items entering the shredder or a buildup of dust in the unit can create a fire hazard. Fire suppression equipment should be specified.

Explosions: Explosions in MSW shredders are numerous. The potential exists for explosions to occur within the shredder or along the outfeed conveyors. Internal explosions are usually directed upwards through the infeed opening while those occuring in the outfeed shoot are directed in all directions. Facility layout and roof design should be specified to reduce potential danger and damage. Explosion suppression equipment should be specified.

Other Safety: Maintenance should be routinely scheduled to avoid unnecessary operator adjustments of online units.

General Environmental: Dust suppression may be necessary. No other emissions are generated.

Cost Analysis

Capital cost range: \$50,000-\$750,000 depending on throughput capacity and manufacturer. However cost is not solely a function of capacity. Reported cost of a 50 TPH shredder ranged from \$75,000-\$750,000. High levels of maintenance and energy costs are associated with all shredders. Expected life-span of units is 15-20 years provided adequate maintenance is provided.(See graphs on Page 5.)

STATE-OF-THE-ARTt

R&D Needs: Shredders have a good overall operating history. Research needs to be done to reduce maintenance requirements and determine the effect of design characteristics on energy requirements, throughput and particle size distribution.

Operating Systems: Greater than 60 operating systems throughout the U.S. and Canada.

Manufacturers: American Pulverizer
Hammermills, Inc.
Williams Patent Crusher, Co.
Tracos Marksman
Many others

Risks: Proven explosion prevention devices do not exist.

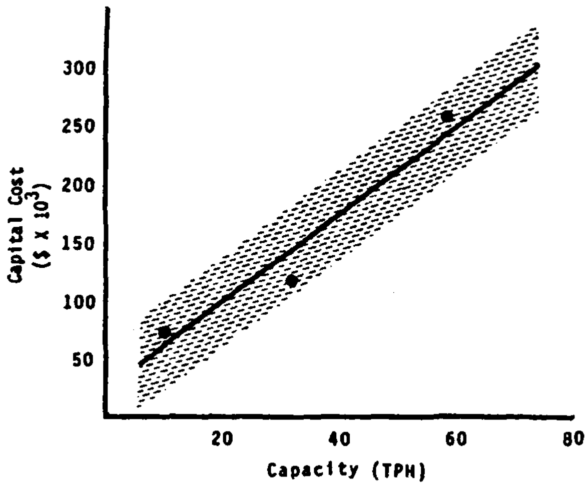
History: Shredders have been in use for many years in the scrap auto processing industry. Their introduction into MSW processing occured in the 1950's. Interest in shredders increased in the 1960's when it was felt that shredding could eliminate the need for daily cover of landfilled waste. The rise of RDF production in the 1970's dramatically increased the use of shredders.

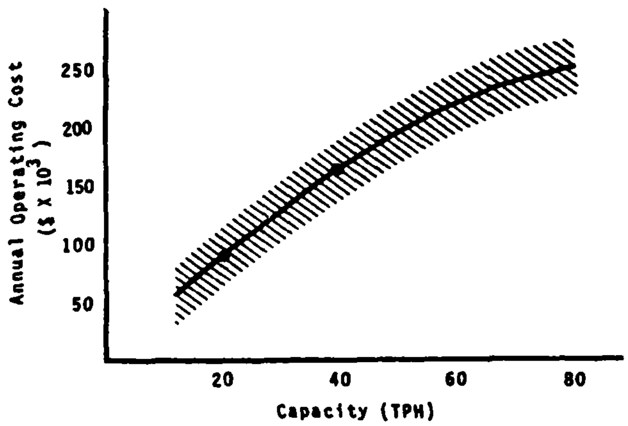
Successes: Shredders have proven themselves in many thousands of hours of operation.

Failures: No major failures have been reported.

Key Problems: Numerous explosions and high maintenance costs.

Other Information: None


300
250
200
150
100
50
Capital Cost ($ X 10^3)
20
40
60
80
Capacity (TPH)


250
200
150
100
50
Annual Operating Cost ($ X 10^3)
20
40
60
80
Capacity (TPH)

COMPONENT DESCRIPTION

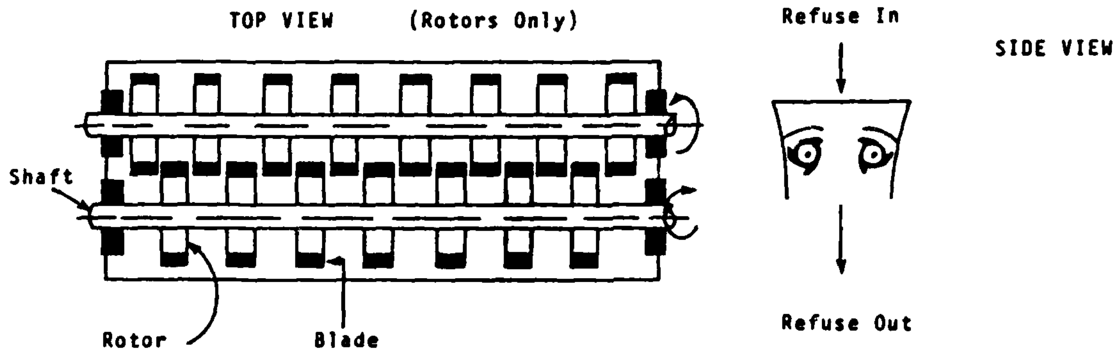
Shredders

Type
Rotary Shear

Types Available - Competing Components
a. Vertical hammermill
b. Horizontal hammermill
c. Rotary shear
d. Ball mill
e. Flail mill

Types Used Commercially
a, b, c

Physical Characteristics



General Description

See Vertical Hammermill, MH-F.

Principle of Operation

Twin horizontally-positioned shafts mounted with knife-edged rotors, rotate in opposite directions, directing the incoming refuse towards the center of the two rotors. The knife edges grab the refuse and through shearing action between the rotors reduce the particle size. Units are typically hydraulically-driven and are reversible to prevent jamming.

Materials of Construction

- Shaft: Hardened alloy steel.
- Rotors: Hardened alloy steel.
- Blades: Hardened alloy steel.

Advantages Over Other Types

- Smaller units (<50 tpd) are available.
- Lower power consumption.
- Can shred problem materials i.e., tires, wire, foam rubber.
- No balling up of product.
- Reduced noise level.
- Reduced dust level.
- Reduced explosions.
- Lower costs.

SIZING CRITERIA

- Unit: Shearing type shredders are available for between 5-75 tpd operations.
- Motor: 460 volt, 3-phase, 60 hz; horsepower will vary with capacity.
- Horsepower: Throughput, nature of material to be processed.
- Infeed opening: Throughput, maximum size of material to be processed.

ACCESSORY COMPONENTS

- Feed conveyors.
- Discharge conveyors.

SUPPORT REQUIREMENTS

Personnel: One additional personnel is needed full-time to operate the shredder above that required to run a facility. Automatic control is feasible. A welder is periodically required.

Training: Training is needed to learn maintenance proce dures. No additional training is needed. Blade resurfacing requires welding.

Skills Required: No special skills are needed to operate the unit. Resurfacing blades requires welding skills plus moderate mechanical skill.

Inspection: Shredders should be routinely inspected for blade wear, bearing wear, and lubrication.

Access: Adequate access on all sides and top for maintenance.

Spare Parts: Replacement blades, bearing lubricant, bearings, drive gear/belt (if applicable).

Permits: No special permits are required.

OPERATIONAL CONSIDERATIONS

General: Shredders are high maintenance units. Pre-sorting of unshreddable or hazardous items such as engine blocks or full gasoline cans is recommended.

Installation: No special installation requirements exist. Units are usually delivered fundamentally intact.

Maintenance: Routine maintenance of blades, bearings, and drive gears is critical to trouble-free operation. Blades require daily inspection and may require weekly resurfacing depending on wear patterns and material. Blade replacement is necessary when resurfacing is impossible.

Controls: Automatic with manual override is preferred. Not all manufacturers have this capability.

MATERIALS HANDLING	Size Reduction	MH-G	P. 3 of 4

Scheduling: 24 hr/day operation is possible, provided the unit is off-line at least a portion of one day per week for blade maintenance.

Downtime: Shredder history is excellent, maintenance is key to limiting downtime.

Other Factors: Oversized items need to be removed or reduced in size prior to entering the shredder.

SAFETY AND ENVIRONMENTAL CONSIDERATIONS

General: Shredders are perhaps the most hazardous single unit operation in a recovery facility. Shear-type shredders are less hazardous than impact types.

Fire Hazard: Combustible items entering the shredder or a buildup of dust in the unit can create a fire hazard. Fire suppression equipment should be specified.

Explosions: Explosions in MSW shredders are numerous. The potential exists for explosions to occur within the shredder or along the outfeed conveyors. Internal explosions are usually directed upwards through the infeed opening while those occuring in the outfeed shoot are directed in all directions. Facility layout and roof design should be specified to reduce potential dangers and damage. Explosion suppression equipment should be specified.

Other Safety: Maintenance should be routinely scheduled to avoid unnecessary operator adjustments of on-line units.

General Environment: Dust suppression may be necessary. No other emissions are generated.

COST ANALYSIS

Capital costs range from $35,000-$300,000 depending on capacity and manufacturer. Same considerations apply as to hammermills.

STATE-OF-THE-ART

R&D Needs: Shredders have a good overall operating history. Research needs to be done to reduce maintenance requirements; to determine the effect of design characteristics on energy requirements, throughput and particle size distribution.

Operating Systems: Greater than 100 systems are in operation throughout the United States and Canada. The number processing solid waste exclusively is unknown. Rotary shears are not as common to solid waste processing as hammermills.

Manufacturers:

- Saturn Mfg., Co.
- Montgomery Industries.
- Garbalizer Mfg., Co.

Risks: Unshreddable items need to be removed manually ahead of the shear.

Other Information: Most units are automatically reversing to prevent jamming.

History: Shredders have been in use for many years in the scrap auto processing industry. Their introduction into MSW processing occurred in the 1950's. Interest in shredders increased in the 1960's when it was felt that shredding could eliminate the need for daily cover of landfilled waste. The rise of RDF production in the 1970's dramatically increased the use of shredders.

Successes: Shredders have proven themselves in many thousands of hours of operation.

Failures: No major failures have been reported.

Key Problems: Numerous explosions and high maintenance costs.

COMPONENT DESCRIPTION

Baler

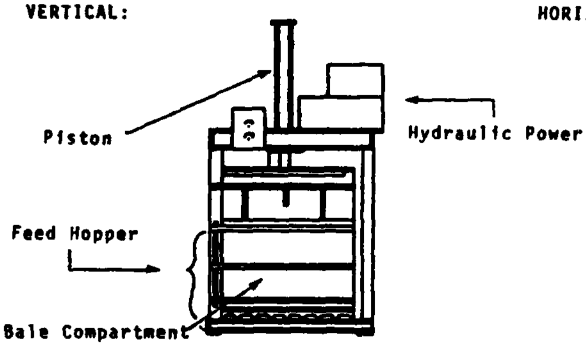
Type
Hydraulic

Types Available
a. Vertical
b. Horizontal

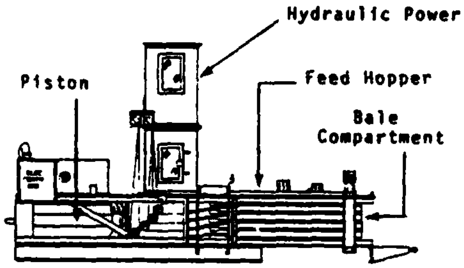
Types Used Commercially
a, b

Physical Characteristics

VERTICAL:



HORIZONTAL:



General Description

In either vertical or horizontal equipment, loose waste is loaded into a feed hopper. The load door is closed compartmentizing the waste. A hydraulically-powered ram compresses the waste into about one-third the cubic space. Metal bands can be used to restrain the bale from expansion. The piston is retracted and the finished bale ejected.

Principle of Operation

Three key elements are: hydraulic power source, piston and ram, and bale compartment. Vertical balers compress up and down, horizontal balers compress side to side. Horizontal units are more common. Automatic bale ejection and metal band bale restraint installers are optional equipment.

Materials of Construction

- Frame - mild steel.
- Piston - alloy steel.
- Ram - hardened steel.
- Hydraulics - pump and motor, various metals, composite rubber hoses.

Advantages Over Other Types

Hydraulic balers are faster and generally more cost-effective than mechanical balers.

SIZING CRITERIA

- Bale size - ht x width x length - dependent on bale compartment dimensions.
- Throughput - tons/hr - dependent on bale size, cycle time, and hp.

ACCESSORY COMPONENTS

- Automatic bale ejection.
- Automatic metal tie installation.

SUPPORT REQUIREMENTS

Personnel: One maintenance; one operation.

Training: Loading rate - cycle time, hydraulic repair.

Skills Required: Welding, motor/pump repair, skip loader operation.

Inspections: Piston wear, hose wear, hydraulic fluid level.

Access: Adequate for front-end loader and maintenance.

Spare Parts: Hoses, hydraulic fluid, pump rotor.

Permits: None.

OPERATIONAL CONSIDERATIONS

General: Baler performance dependent on uniform waste flow.

Installation: Insure adequate maintenance clearance.

Maintenance: Periodic and frequent due to harsh operating conditions.

Controls: Automatic or manual bale weight control.

Scheduling: Continuous operation possible.

Downtime: Frequent due to high load/stress conditions.

Other Factors: Minimize vibrations and shock loadings.

SAFETY AND ENVIRONMENTAL CONSIDERATIONS

General: Balers are constructed to be safe provided recommended procedures are followed.

Fire Hazard: Moderate - flammable liquids may be extruded during compression, provide sprinklers and fire extinquishers.

Explosion: Low - explosion suppression equipment usually not specified.

Other Safety: Operator training important to reduce risks.

General Environmental: Dust from general handling as opposed to baling per se should be vented.

COST ANALYSIS

Cost varies widely between manufacturers. Baling systems for disposal of solid waste often include a complete facility, much like a transfer station. Balers for recovered materials (metal, currugated paper, etc.) are much different, and their costs also vary as a fluctuation of material.

See manufacturer for price quotes based on intended use.

STATE-OF-THE-ART

R&D Needs: Baling characteristics of process/combustion residue.

Operating Systems: Many. Good example is HMDC Baler at North Arlington, New Jersey.

Manufacturers: Numerous.

Risks: Technical risks low.

COMPONENT DESCRIPTION

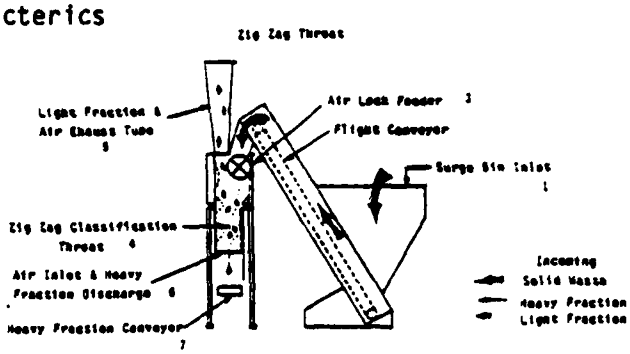
Air Classifier

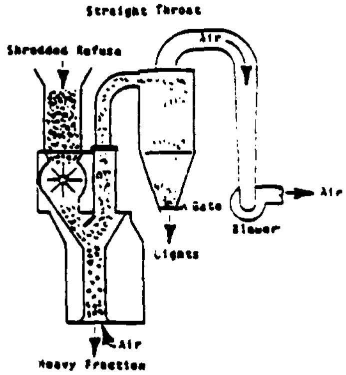
Type
All

Types
- a. Zig Zag
- b. Straight throat
- c. Rotary drum
- d. Concentric-tube
- e. Duke throat
- f. Utah throat
- g. Vibrating

Types Used Commercially
a, b, c, d, g

Physical Characterics





General Description

Air classifiers are used to separate the light combustible organic fraction from the heavy non-combustible inorganic fraction. The separation of material is accomplished aerodynamically using a moving stream of air. Air classification can be preceded by shredding or trommeling to decrease particle size, but this is not mandatory.

Principle of Operation

In a typical configuration air is moved through the classifier by induced draft. Incoming refuse is controlled by an air lock prior to being dropped into the moving air stream where it is turbulently mixed. Rotary type units use the rotating throat section to increase refuse to air contact. Light particles are incorporated into the air flow and carried out of the throat section. Downstream of the throat, a settling chamber is provided where air velocity is greatly reduced and the light materials drop out. Filters are usually provided after the settling chamber to remove incorporated dust and other fines. Heavy materials are not drawn up with the air stream and fall out of the unit by the force of gravity.

Materials of Construction

- Throat - heavy steel, abrasion-resistant alloys.
- Fans - heavy duty industrial draft fans.
- Other items - steel construction.

Advantages Over Other Types

Rotary-type classifiers provide higher levels of refuse to air contact and the rotating action causes dumped items to break apart.

Straight and zig zag-type classifiers have fewer moving parts which contributes to lower overall operating and maintenance costs.

SIZING CRITERIA

- Throat - dependent on type - drums are between 10-20 ft in diameter, straight and zig zag throats are between 1-15 ft in diameter.
- Fan Horsepower - 250-1,000
- Air Flow (cfm) - maximum reported is 720,000 for a 200 tph unit.
- Height - larger units can approach 50 ft.(See graph on Page 4.)

ACCESSORY COMPONENTS

Infeed conveyors and hoppers; light fraction collection bin or conveyor, heavy fraction collection bin or conveyor. All additional equipment is typically supplied by the manufacturer.

SUPPORT REQUIREMENTS

Personnel: No additional personnel are required to operate an air classifier.

Detailed breakdown of operational manpower needs has not been done for air classifiers.

Training: Operational and maintenance training is required and is usually supplied by the manufacturer.

Skills: No special skills are required.

Inspections: Routine inspection as recommended by the manufacturer. Periodic monitoring of controls required.

Access: Adequate for inspections and maintenance.

Spare Parts: Rotary air lock tip seals, lubricant, redundant fans may be specified, bearings.

Permits: No federal permits required, local air pollution permit may be required in certain areas.

OPERATIONAL CONSIDERATIONS

General: Efficiency of separation is dependent on many factors including: air velocity, particle size and moisture content. No configuration has been proved superior.

Installation: Crane needed, approximately 3 to 4 week for installation by 3-4 man crew.
Maintenance: Routine greasing and lubrication needed, linings if provided may need periodic replacement.

Controls: Automatic controls for air damper, feed rate. Remote visual monitoring of units has been used successfully.

Scheduling: 24 hr operation possible.

Downtime: Experience has shown that after initial startup problems, downtime is minimal.

Other Factors: Detailed breakdown of yearly costs for air classifier operation is not available.

SAFETY AND ENVIRONMENTAL

General: Little or no safety problems were noted with air classifiers.

Fire Hazard: Minimal.

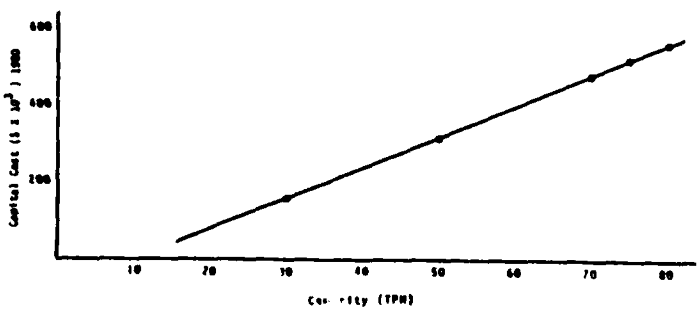
Explosions: Minimal.

Other Safety: None noted.

General Environmental: Dust control and air clean up equipment is required.

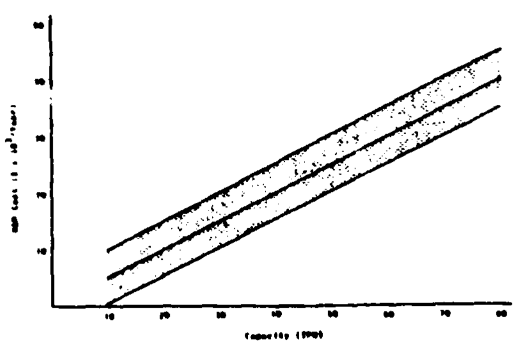
COST ANALYSIS

A cost of $6,000 per ton of design capacity can be assumed. Air pollution control equipment will add an additional $40,000-80,000 per facility. Installation costs are excluded but can range up to $100,000.



STATE-OF-THE-ART

R&D Needs: Determination of optimum design parameters for MSW feed. Small-scale units are not generally available. Separation efficiency improvements. Energy requirements reduction.



Operating Systems:

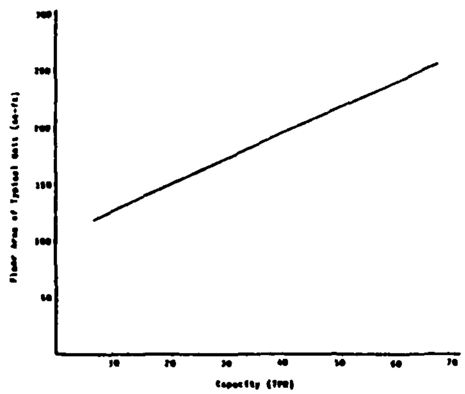
- Ames, Iowa - Straight Throat.
- Milwaukee, WS - Zig Zag Throat.
- Chicago, IL - Vibrating Throat.
- Baltimore County, MD - Concentric Tube Throat.
- Monroe County, NY - Rotary Drum.

MATERIALS HANDLING	Separation	MH-I	P. 4 of 4

Manufacturers:

- Straight Throat - Rader Pheumatics, Portland, OR, The Heil Co, Milwaukee, WS.
- Zig Zag Throat - Mac Equipment, Sabetha, KS.
- Vibrating Throat - Triple/S Dynamics, Dallas, TX.
- Concentric Tube Throat - Undetermined.
- Rotary Drum Throat - Iowa Mfg, Cedar Rapids, IA.

Risks: Little risk associated with air classifiers.



COMPONENT DESCRIPTION

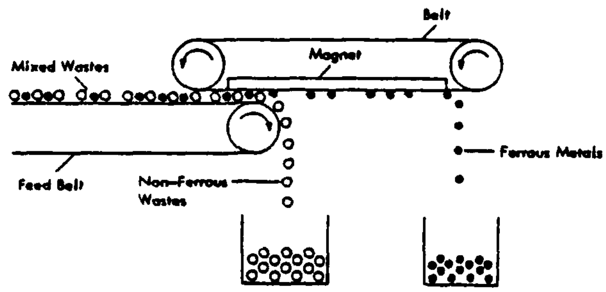
Magnetic Separator

Type
Belt

Types Available - Competing Components
a. Belt
b. Rotary drum

Types Used Commercially
a, b

Physical Characteristics



General Description

Magnetic separators are used primarily to remove ferrous metals from MSW. Removal of the 5-8 percent ferrous fraction has three advantages: 1) production of a highly saleable product 2) reduction of wear on subsequent processing equipment, and 3) an increase in per pound Btu content over raw MSW.

Principle of Operation

The separator is positioned over the MSW conveyor. The magnetic attraction of the separator lifts the ferrous metals and holds them as the remaining MSW is deposited into bins or onto conveyors for further processing. The ferrous fraction is carried on the moving belt to a designated point where the magnetic attraction is stopped. The separated material then falls off the belt to be further processed.

Materials of Construction

- Belt - stainless steel.
- Other items - machine steel, hardened steel.
- Magnets - electric or permanent type.

Advantages Over Other Types

Lifts material off conveyor, thereby reducing wear; focused magnetic field.

SIZING CRITERIA

- Belt - width of belt
- Belt speed - throughput, percent separation required.
- Magnetic field penetration (typically 12-24 in).

ACCESSORY COMPONENTS

- Collection bins.
- Conveyors.

SUPPORT REQUIREMENTS

Personnel: No extra personnel are needed to operate a magnetic separator.

Training: No special training is needed, maintenance training supplied by manufacturers.

Skills Required: Mechanical for maintenance.

Inspections: Belt inspection on a weekly basis.

Access: Adequate for maintenance.

Spare Parts: Belts wear out regularly, bearings.

Permits: No permits required.

OPERATIONAL CONSIDERATIONS

Installation: Optimum installation is necessary for separation efficiency.

Maintenance: Belt maintenance should be on a regular basis.

Controls: No controls needed.

Scheduling: 24 hour operation possible.

Downtime: Belt failures is the only expected downtime.

SAFETY AND ENVIRONMENTAL CONSIDERATIONS

General: No major safety or environmental hazards are associated with magnetic separators.

Explosion: Dust levels should be controlled.

COST ANALYSIS

Capital cost typically includes the separator and power supply but does not include supports or intermediate material handling conveyors.(See graph on Page 3.)

Life Cycle Cost

Total cost for 10 years is approximately $100,000 (assumed 10 years amortization 50 tph throughput, 2,000 hr/yr operation).(See graph on Page 3.)

STATE-OF-THE-ART

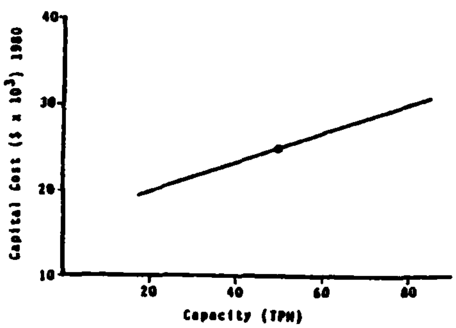
R&D Needs: Few.

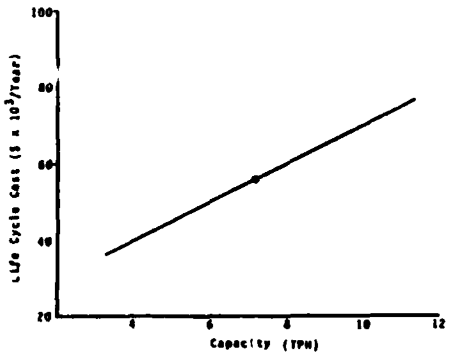
History: Magnetic separators have been in use for many years in various industries. Specifically, the scrap automobile industry, iron foundries, and other scrap steel operations.

Successes: Magnetic separators generally pay for themselves within the first year of municipal operation provided ferrous markets exist.

Failures: No failures were noted.

Key Problems: Belt life, no additional problems were noted.





MATERIALS HANDLING	Magnetic Separator	MH-K	P. 1 of 3

COMPONENT DESCRIPTION

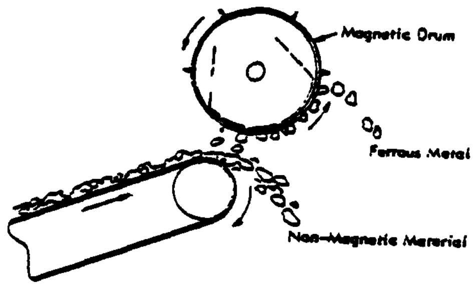
Magnetic Separator

Type
Drum

Types Available - Competing Components
a. Belt
b. Rotary Drum

Types Used Commercially
a, b

Physical Characteristics



General Description

Magnetic separators are used primarily to remove ferrous metals from MSW. Removal of the 5-8 percent ferrous fraction has three advantages: 1) production of a highly saleable product 2) reduction of wear on subsequent processing equipment, and 3) an increase in per pound Btu content over raw MSW.

Principle of Operation

The separator is positioned over the MSW conveyor. The magnetic attraction of the separator lifts the ferrous metals and holds them as the remaining MSW is deposited into bins or onto conveyors for further processing. The ferrous fraction is carried on the rotating magnetic drum to a designated point where the magnetic attraction is stopped and the separated material then falls off the belt to be further processed.

Materials of Construction

- Drum - stainless steel, hardened steel.
- Other items - machine steel, hardened steel.
- Magnets - electric or permanent type.

Advantages Over Other Types

Lifts material off conveyor thereby reducing wear, no belts to wear out, lower maintenance costs, dual drum systems have been demonstrated.

SIZING CRITERIA

- Drum - width of belt (See graph on Page 3.)
- Belt speed - throughput, percent separation required.
- Magnetic field penetration (typically 12-24 in).

ACCESSORY COMPONENTS

- Collection bins.
- Conveyors.

SUPPORT REQUIREMENTS

Personnel: No extra personnel are needed to operate a magnetic separator.

Training: No special training is needed, maintenance training supplied by manufacturer.

Skills Required: Mechanical for maintenance.

Inspections: Drum inspection on a weekly basis.

Access: Adequate for maintenance.

Spare Parts: Lubrication.

Permits: No permits required.

OPERATIONAL CONSIDERATIONS

Installation: Optimum installation is necessary for separation efficiency.

Maintenance: Maintenance should be scheduled on a regular basis.

Controls: Minimal controls needed.

Scheduling: 24 hour operation possible.

Downtime: Little downtime is expected.

SAFETY AND ENVIRONMENTAL CONSIDERATIONS

General: No major safety or environmental hazards are associated with magnetic separators.

Explosion: Dust levels should be controlled.

COST ANALYSIS

Capital cost typically includes the separator and power supply but does not include supports or intermediate material handling conveyors. (See graph on Page A-38).

MATERIALS HANDLING	Magnetic Separator	MH-K	P. 3 of 3

Total cost for 10 years is approximately $50,000 (assumes 10 yr amortization, 50 tph throughput, 2,000 hr/yr operation).(See graph on Page 3.)

STATE-OF-THE-ART

R&D Needs: Focus of magnetic field, multiple drum systems.

Operating Systems: Charleston, W.Va; and others.

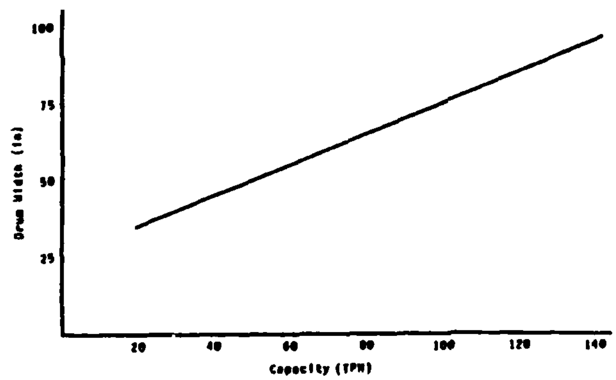
Risks: Few.

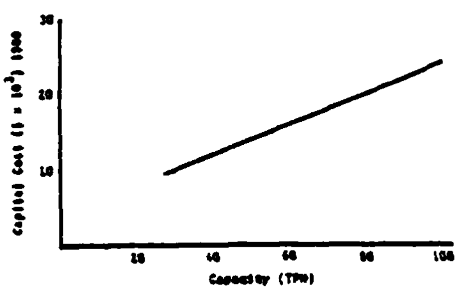
History: Magnetic separators have been in use for many years in various industries. Specifically, the scrap automobile industry, iron foundries, and other scrap steel operations.

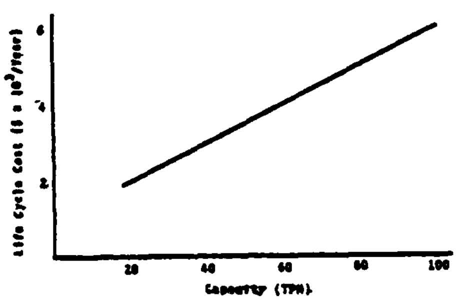
Successes: Magnetic separators generally pay for themselves within the first year of municipal operation provided ferrous markets exist.

Failures: No failures were noted.

Key Problems: No major problems were noted.







COMPONENT DESCRIPTION

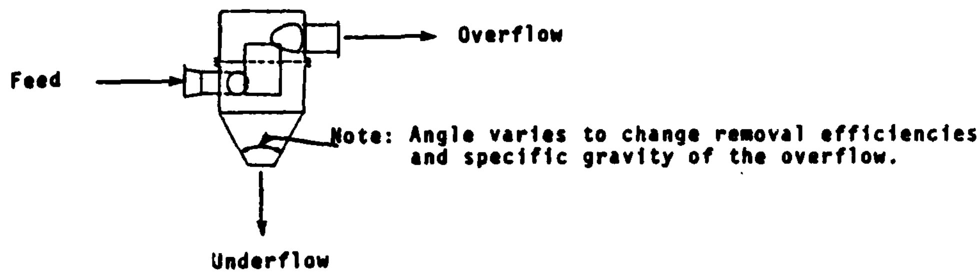
Heavy Medium Separators

Type
Cyclone

Competing Components
a. Float-sink separators

Types Used Commercially
Cyclone, Float-sink

Physical Characteristics



General Description

A cylindrical tank with a conical bottom. Inflow of the liquid feed is situated to induce the tank contents to spin. Guide tubes or vanes in the center of the tank serve to guide the vortex that is created and maintain the separation of light and heavy fractions around the inlet and overflow outlet.

Principle of Operation

Separation is accomplished based on the specific gravity of the materials introduced. Heavy materials are removed in the underflow while light materials are removed in the overflow. Depending on the flow velocity, angle of the conical section, and specific gravity of the fluid medium, separation can be accomplished for specific gravities of 1.3 to 3.8 using a heavy medium consisting of fine magnetic or ferrosilicon particles in water.

Materials of Construction

Mild steel for most components. Wearing surfaces such as the inside of the cone may be coated with a hard ceramic material or made of hardened steel.

Advantages Over Other Types

Permits separation of aluminum from the heavier ferrous materials. Medium is a mixture of water and fine solid particles, reducing the problem of contamination of the feed materials.

SIZING CRITERIA

Flow rates through the separator influence the specific gravity of the materials that are separated. The system, therefore, should be carefully sized and matched to the amount of feed material processed.

STATE-OF-THE-ART

History: The separation of coal, ore, and minerals by this technology has been in existence for 25-30 years. Tests to determine the feasibility for use on waste materials have been underway in Europe since 1975.

Successes: The recovery of various metals from scrap automobiles is common.

Key Problems: In the facility of automobile scrap, oil which adheres to the input material contaminated the heavy medium, requiring the addition of oil/water separation. Wear of the cone of the separator due to abrasion.

MATERIALS HANDLING	Aluminum Separator	MH-M	P. 1 of 3

COMPONENT DESCRIPTION

Aluminum Separator

Type
Eddy Current Separator

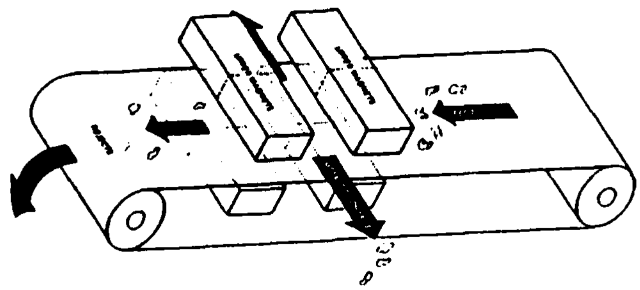
Types Available

a. Eddy Current Separator
b. Dense Media Separator
c. Electrostatic Separator
d. Air Knife

Types Used Commercially

a, b

Physical Characteristics



General Description

Vibrating pan conveyer feeds belt conveyor, which is stationed between opposing set of electromagnets. Material passes along conveyors into varying magnetic field. Current induced in conductors. Second magnetic field (opposing) induces motion in conducting materials across the belt and off. Conductivity/density is twice as high for aluminum as for other non-ferrous conductors, permitting selective recovery given the proper field strength and position.

Materials of Construction

No data available.

Advantages Over Other Types

- Essentially dry; no wastewater discharge.
- Available in standard design and capacity; scale-up achieved with redundancy.

SIZING CRITERIA

- Design is proprietary; standard size of 4 ton/hours (~200 ton/hour refuse equivalent).
- Recovery efficiency increases as throughput is reduced for a given design capacity.
- Multiple units recommended for larger capacity systems.

ACCESSORY COMPONENTS

- Vibrating pan feed conveyor.
- Discharbe bin/hopper for product.

SUPPORT REQUIREMENTS

Personnel: System monitoring is required; estimated 0.25 people full time.

Inspections: Belt wear, product quality.

Access: Accessible from allsides.

Spare Parts: Belts; other data not available.

Permits: None.

OPERATIONAL CONSIDERATIONS

General: Flow metering is critical to good recovery efficiency and quality control.

Installation: System vibration must be accounted for in structural design.

Maintenance: Apparently a low maintenance operation, but regular inspection of feed and conveyance systems is recommended.

Controls: Power only; typically no surge capacity to control flow from front-end processing system.

Downtime: As necessary (infrequent)

SAFETY AND ENVIRONMENTAL CONSIDERATIONS

General: Vibration control necessary; noise control not a problem.

Fire Hazard: Low.

Explosion: Low.

Other Safety: Shields designed as part of system to deflect moving material.

General Environmental: No problems incountered or anticipated.

COST ANALYSIS

Limited cost data available. Capital cost of 4 ton/hour separator is approximately $300,000 with supporting components, excluding necessary front end processing. Specifications and power requirements are listed below:

- Power: 3 phase, 450-volt.
  27 kilowatts
- Cooling water: 130 gallons/hours (recirculated).
- Belt: 0.040 in nylon with stainless steel splice (replaceable).

Live cycle: no data available

STATE-OF-THE-ART

R&D Needs: Extensive research has been conducted on eddy current separation by NCRR and others. The applicability and limitations of this system are well known as a result. Extended operating experience under a variety of feed conditions needed before additional R&D can be identified.

Operating Systems: New Orleans (Recovery I).

Manufacturers: Combustion Power Company.

Fields: Capital cost is high, so dedication to debugging and process modification may be necessary to guarantee payback. Product market specifications may be difficult to meet in some instances.

History: Eddy current separators have been applied to solid waste on a test scale for many years. First full scale installation was Ames, Iowa, in 1975, but system did not produce a marketable product. Subsequent installation at Recovery I was successful. System is used for research by NCRR and commercial scale testing.

Key Problems: Fine-tuning system to recover acceptable product from a given waste flow and condition.

REFERENCES

1. National Center for Resource Recovery:

   - An investigation of Aluminum Recovery Using an Eddy Current Separator. TR 77-5, October 1978.
   - Aluminum Recovery from Municipal Solid Waste using an Eddy Current Separator. Tr 80-8, June 1980.

2. Soldono, Louis P. Recovery of Aluminum from Municipal Solid Waste at Recovery 1, New Orleans. EPA 600/52-81-121, July 1981.

3. Combustion Power Company, "Al Mag" Commercial Literature.

COMPONENT DESCRIPTION

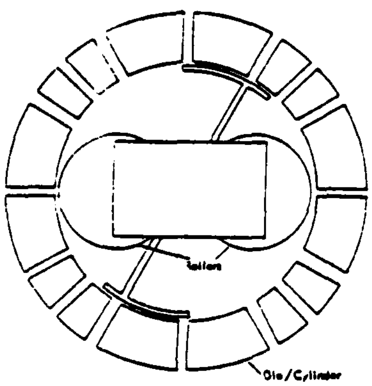
Pelletizer

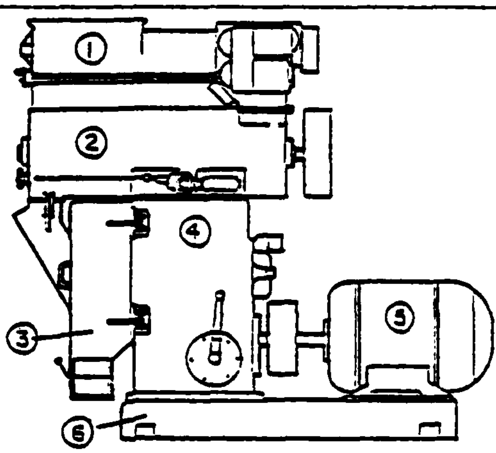
Type
Pellet Mill

Types Available
- a. Pelletizers
- b. Briquetters
- c. Cubetters
- d. Extruders

Types Used Commercially
a

Physical Characteristics





1. VARIABLE FEEDER
2. CONDITIONING CHAMBER
3. DIE AND ROLLER ASSEMBLY AREA
4. SPEED REDUCTION DEVICE
5. PRIME MOVER
6. BASE

General Description

Pelletizers are used to form fine fluff or other RDF types into pellets of a specific size and shape. The pellets can be bound together chemically or using the free moisture in the solid waste. A variety of pellet sizes and shapes can be roduced, with the intention of generating a product that is similar to coal in its handling and combustion characteristics.

Principle of Operation

Shredded, classified soil waste is first fed into the conditioning chamber. From there the material is introduced into the center of the die using a screw feeder or other device. Two rotating rollers force the material through the die. Blades surrounding the outside of the die cut the pellets to size. On newer units, the die rotates and the rollers remain stationary.

Materials of Construction

Dies: No data available.

Advantages Over Other Types

- Capable of continuous operation at a higher capacity than other configurations.

SIZING CRITERIA

- Pellet size should be based upon characteristics of existing coal handling systems. Typical RDF pellet thickness is 1/2 to 3/4 inch, and length averages 1 inch.

- Standard designs are available, but typical capacity is much lower than commercial RDF production systems, therefore requiring multiple units.

ACCESSORY COMPONENTS

- Feed conveyor.
- Storage bins.

SUPPORT REQUIREMENTS

No data are available on routine support requirements for commercial RDF pellet mills. Die wear is known to be a problem, and spare dies would be most expensive spare parts inventory.

OPERATIONAL CONSIDERATIONS

Installation: Pelletizers are delivered essentially ready for startup. Substantial structural support is necessary (die speeds typically range from 130 to 400 rpm).

Maintenance: Limited data are available on equipment maintenance and component life.

Controls: Variable speed drives are often used to adjust for variations in feedstock composition.

Scheduling: Continuous operation is possible. Visual inspections should be scheduled, as well as routine component replacement.

Downtime: Approximately 5 to 10 percent downtime can be expected for inspection and maintenance.

SAFETY AND ENVIRONMENTAL CONSIDERATIONS

General: No safety or environmental hazards are associated with pellet mills.

Explosion: Minimal risk.

COST ANALYSIS

No long-term operating data available.

STATE-OF-THE-ART

R&D Needs

- Effect of moisture, die speed, and other operating variables on pellet integrity.
- Combustion characteristics of dRDF relative to other RDF forms.
- Maintenance requirements for commercial dRDF production (>500 tpd).

Operating Systems: Baltimore County, Maryland.

Risks: Technical scaleup of pelletizing systems may encounter maintenance problems impeding continuous operation.

History: The ring type mechanical extrusion mill has nearly universal application, and within relatively broad boundary conditions, has had the highest degree of success in producing pelleted refuse-derived fuel or DRDF.

The first successful pellet mill which used steel dies and rolls was developed in 1931. This unit consisted of a flat steel die with four steel rollers on its surface. Feedstock was fed to the die face, distributed and forced through the die by rollers. The pellet extrusions were cut off or broken off by multiple knives.

The ring-type pellet mill, which uses dies and rollers in a vertical plane, was developed in 1934. Conditioned feedstock is fed and distributed within the working volume by gravity, mechanical deflectors, and centrifugal force. Pressure caused by rotation of the die and rollers compacts the feedstock into a mat on the face of the die and develops the forces which extrude the material through the die holes, forming it into pellets. Adjustable knives shear the extruded material to the desired pellet length. In most modern pellet mills, the die is driven and the rollers are stationary on their axes, but are free to rotate upon contact with the die and the material being pelleted. Two rollers are usually used. Nearly all currently manufactured pellet mills include a feeder, conditioning chamber, die and roller assembly, speed reduction device, prime mover, and a common base.

REFERENCES

1. Hathaway, S. A. et al. Production and Use of Densified Refuse-Derived Fuel (DRDF) in Military Central Heating and Power Plants. CERL Technical Report E-159, March 1980

2. Trezek, G. J. et al. Overview of Prepared Fuels Technology. Presented at the International Conference on Prepared Fuels and Resource Recovery Technology, Nashville, Tennessee, February 10-13, 1980.

3. Marsh, J. R. et al. Control and Disposal of By-Products from Refuse-Derived Fuel Production and Use. SCS Engineers, Long Beach, California, 1979.

APPENDIX B

AIR POLLUTION CONTROL EQUIPMENT (APC)

AIR POLLUTION CONTROL	Baghouse	APC-A	P. 1 of 4

COMPONENT DESCRIPTION

Dust Collectors

Type
Filtration Devices

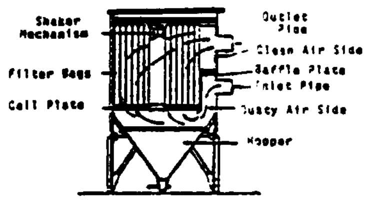
Types Available - Competing Components

a. Fabric filters
b. Granular bed filters
c. Fiber bed filters
d. Viscous filters
e. Electrostatically augmented filters

Types Used Commercially
a, b

Physical Characteristics

Single-Compartment Baghouse Filter



General Description

Unit consists of groups of large segmented chambers each equipped with fabric filter bags. The cylindrical or envelope-shaped filters can be constructed in a variety of sizes and arranged so that continuous removal of the collected material is possible. Filter units are cleaned mechanically or by using pressure pulses created by compressed air. Collected dust is removed from hoppers located under the filters.

Principle of Operation

Particulate matter is removed by filtering the particulate-laden gas stream through a filter media barrier. The barrier, and more importantly, the collected particulate matter which coats the barrier, acts to prevent particles from passing through. The collection mechanisms are direct interception and inertial impaction for the larger particles and diffusion impact (Brownian motion) for the smaller particulate.

Materials of Construction

- Filtering media - granular media (sand, gravel) glass fibers, woven or felted fabrics (Nylon, polypropylene, cotton, wool, Teflon, Nomex, glass, Orlon).
- Shell and structural members - Carbon steel.
- Baffles - Carbon steel, 316 Stainless steel.
- Cleaning mechanism - Carbon steel, 316 Stainless steel.

Advantages Over Other Types

- High collection efficiency for fine particles.
- Process uses dry collection of dust thus minimal dust treatment is needed.
- Fairly low pressure drop is needed.

SIZING CRITERIA

- Air to cloth ratio - 6 to 1 or less (use 4)
- Cleaning method - reverse air, pulse jet
- Flue gas temperature - generally between 300-500°F
- Fabric filter type - silicone coated
- Pressure drop - 3-10 in water column

Size of filter (typical)

Surface area of filter media needed = air to cloth ratio x volume of gas to be cleaned. (See graph on Page 4.)

ACCESSORY COMPONENTS

- Dust-handling equipment.
- Ducting, dampers, stack, fans.
- Broken bag detector.
- Gas cooling equipment (radiant cooler, spray cooler, dilution air).
- Precleaner (mechanical collector).

SUPPORT REQUIREMENTS

Personnel: operation labor - 2 to 4 man-hr/shift; maintenance labor - 1 to 2 man-hr/shift.

Tráining: Operator training required (usually supplied by manufacturer and/or vendor.

Skills Required: General mechanical and electrical.

Inspections: General inspection (8 hr of operation); detailed inspection (500-1,000 hr of operation).

Access: Access to replace filter units needed.

Spare Parts: Filter media (bags).

Permits: Air pollution control.

AIR POLLUTION CONTROL	Baghouse	APC-A	P. 3 of 4

OPERATIONAL CONSIDERATIONS

General: Must keep gas above dew point and below temperature tolerance level of fabric.

Installation: Close as possible to emission source.

Maintenance: Routine maintenance needed for media dust removal system. Must replace bags as needed.

Controls: Bag cleaning can be controlled by pressure drop on system.

Scheduling: Continuous operation.

Downtime: Units are constructed in sections for redundancy, thus total system downtime can be minimized.

SAFETY AND ENVIRONMENTAL CONSIDERATIONS

Fire Hazard: Provide temperature and spark protection for fabric filter bags. Not required for gravel media filter units.

Explosion: Must consider explosion potential and adjust design to minimize and/or accomodate it.

General Environmental: Must dispose of collected material in an environmentally acceptable manner.

COST ANALYSIS

Cost of filtration system is dependent upon (1) type of fabric and air-to-cloth ratio; (2) intermittent or continuous duty; (3) pressure or suction-type construction; (4) standard or custom design; (5) method of cleaning; (6) materials of construction.

Life Cycle Analysis: Equipment life - low = 5 yr; average = 20 yr; high = 40 yr.
Fabric filter bags - low = 0.3 yr; average = 1.5 yr; high = 5 yr.

Total Capital Cost

Total cost - purchased equipment cost + installation costs.(See graph on Page 4.)
Direction installation costs = 0.56 x purchased equipment costs.
Indirect installation costs = 0.35 x purchased equipment costs.

Operating Costs Components

- Labor - 3 to 5 man-hours/shift.
- Electrical power = 0.5 hp/1,000ft^2 of cloth.
- Waste disposal = as needed.

STATE-OF-THE-ART

R&D Needs: Ways to extend life of filter media, electrostatic augmentation.

AIR POLLUTION CONTROL	Baghouse	APC-A	P. 4 of 4

Manufacturers:

- American Air Filter.
- Standard Havens.
- Western Precipitation.

Risks: Explosion and fire hazard if not properly designed or improper filter media selected.

History: Earliest models of fabric filter units consisted of manually shaken filter sleeves hung in rows and tied together at the bottom. In 1881 a mechanized shaking device was introduced. Improvements in filter media and shaking technique have constantly been made since this device was originally introduced.

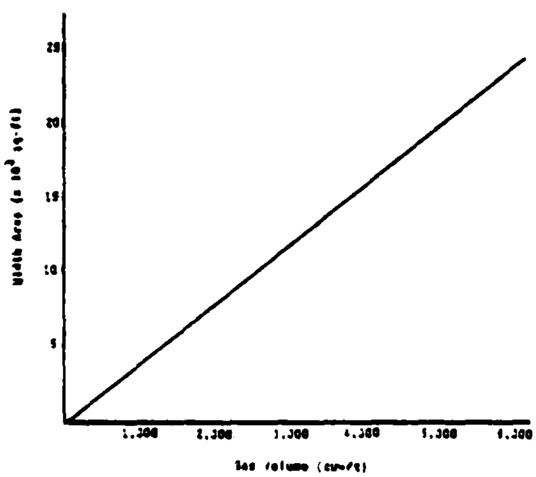
Successes: Filtration devices have been installed on numerous industrial processes but their use is primarily limited by temperature and moisture content of the gases or other characteristics of the dust or flue gas. Two fabric filter installations on municipal incinerators exist, however their success has been limited. These are East Bridgewater and Framingham, Massachusetts. A 9000 ACFM has been successful with 99.8% removal when operating at an air-cloth-ratio of 6 to 1 or less.

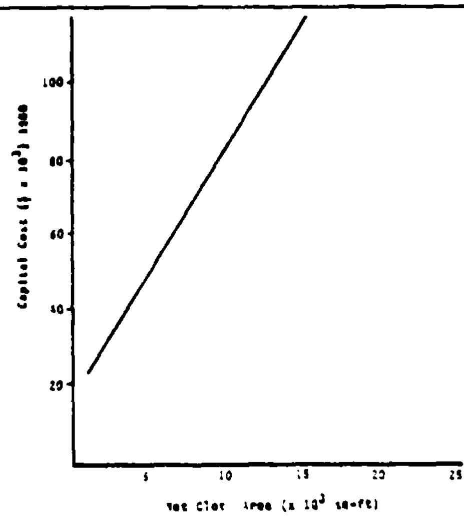
Failures: The East Bridgewater, Massachusetts facility has had problems of bag and bag house corrosion and periodic high opacity observations have persisted. Since baghouse operation is sensitive to temperature and humidity, municipal incinerators with highly variable imput refuse heat and moisture content must have a very tight control system to guarantee proper operation. The problem of fabric deterioration must be controlled by special coatings or pretreating of the input gas stream with neutralizing chemicals.

Key Problems: Filter media problems - fabric life can be shortened by abrasive dusts, sticky dusts, corrosive gases, high temperature gases, and in general, dusts which "bund" the filter media by not being capable of being removed from the media.

REFERENCES

1. Capital and Operating Costs of Selected Air Pollution Control Systems, U.S. EPA 450/5-80-002, Del. 1978.
2. A Review of Standards of Performance For New Stationary Source Incinerators, EPA Contract 68-02-252.





AIR POLLUTION CONTROL	Cyclone	APC-B	P. 1 of 4

COMPONENT DESCRIPTION

Mechanical Collectors

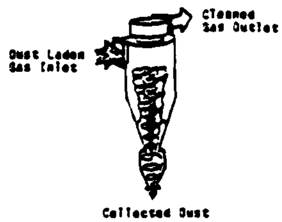
Type
Cyclone

Types Available
- a. Settling chambers
- b. Intertial separators
- c. Reverse flow cyclone
- d. Multicyclones
- e. Scroll collectors

Types Used Commercially
a, b, c

Physical Characteristics

Conventional Reverse Flow Cyclone



General Description

Cyclones consist of an inlet section, a cylindrical barrel, a conical transition from the barrel to a dust outlet, a gas outlet pipe and a dust container below the dust outlet. High efficiency cyclones are often arranged in parallel in multiple cyclone units with common gas inlets and outlets.

Principle of Operation

Mechanical collectors function to remove particles from the gas stream by enhancing the inertia and momentum or gravitational forces which act upon the particles. Settling chambers reduce the velocity of the gas stream to the extent that the particles settle under the force of gravity. Inertial separators cause an increase in gas velocity and rapid changes in flow pattern, thereby causing particles to separate from the gas. Cyclones achieve particle/gas separation by increasing the centrifugal force imparted to the suspended particles which are then forced into the cyclone walls and collected.

Materials of Construction

- Cyclone body - mild carbon steel, abrasion-resistant steels.
- Shell for multicyclone units - mild steel.
- Dust hopper - mild steel.

Advantages Over Other Types

- Low cost.
- High tolerance to excessive temperatures and abrasive dust.
- Low space requirements.
- Dry disposal of particulate matter.
- Low maintenance and operational manpower requirements.
- Simple to operate.

SIZING CRITERIA

- Inlet velocity (49-59 ft/s).
- Pressure drop (0.07-0.25 psi).

ACCESSORY COMPONENTS

- Inlet ducting and dampers.
- Dust removal hopper and rotary air lock valves.

SUPPORT REQUIREMENTS

Personnel: No specialized operating personnel. Generally these devices are simple to operate.

Training: No training required.

Skills Required: None.

Inspections: Inspect for excessive wall roughness, dust buildup, air leaks, and unequalized air flow.

Spare Parts: None required.

Permits: Air Pollution Control.

OPERATIONAL CONSIDERATIONS

General: Mechanical collectors generally are not adequate to control incinerator emissions to meet most air quality standards.

Maintenance: Cyclone units generally require minimal maintenance.

Controls: Minimal controls are required.

Scheduling: Continuous operation.

Downtime: Units can be constructed in modules for redundancy, thus total system downtime can be minimized.

SAFETY AND ENVIRONMENTAL CONSIDERATIONS

Fire Hazard: Minimal.

Explosion: Minimal.

General Environmental: Must dispose of collected material in an environmentally acceptable manner.

COST ANALYSIS

Equipment costs not including installation, freight, taxes, etc. = $0.50 to $0.75/acfm (multicyclone unit with 12" diameter cyclones). Operating costs are equal to the expenses associated with fan power (see Power Requirements).

Life Cycle Analysis - Units generally last 10-15 years.

Power Requirements:

$$\text{kwh} = \frac{0.746\ (\text{cfm})\ (P)\ (SG)\ (H)}{6{,}356n}$$

CFM = volumetric flow rate, acfm.

P = pressure.

SG = specific gravity as compared to air @ 70°F, 29.92 in Hg.

H = hours of operation.

n = efficiency, usually 60-70%.

STATE-OF-THE-ART

R&D Needs: These are well established devices and their performance is fairly well understood.

Operating Systems: Should only be used as gas precleaners upstream of scrubbers, ESP's or fabric filters.

Manufacturers:

- American Air Filter.
- Joy Manufacturing Co.
- Air Pollution Industries, Inc.
- Aget Manufacturing Co.
- American Standard.

Risks: Mechanical collectors have low efficiency for fine particles.

History: Because of their simplicity and lack of moving parts, settling chambers, momentum separators and cyclones have a long history of use. However, in recent years because of more stringent air pollution standards, their use as a final control device has been limited.

AIR POLLUTION CONTROL	Cyclone	APC-R	P. 4 of 4

Successes: There are numerous installations where mechanical collectors and more specifically, settling chambers and multi-cyclone units, have been applied as precleaners prior to fabric filter or electrostatic precipitation units. These units by themselves are not generally sufficient to meet current air quality standards.

Failures: Since mechanical collectors should not be considered as a final control technology, discussion of device failure is referenced to their use as precleaners. Failure can result from improper design (cyclone geometry not appropriate for gas volume and particle size to be collected), or inadequate maintenance.

Key Problems: Cyclones and multicyclones should not be applied to conditions where dust will adhere to the cyclone and dust hopper walls or where the dust is very fine. Specific materials should be used when abrasive or corrosive conditions occur.

COMPONENT DESCRIPTION

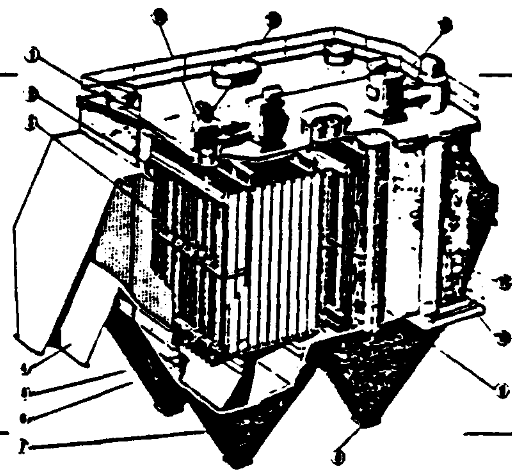
Electrostatic Precipitators

Type
High Voltage-Single Stage

Types Available
- a. High voltage-single stage
- b. Low voltage-two stage
- c. Wet wall
- d. Dry wall
- e. European design
- f. American design

Types Used Commercially
a, d, e, f

Physical Characteristics



1. Support insulators
2. Discharge system
3. Rapping mechanism for discharge system
4. Gas-distribution screens
5. Rapping mechanisms for collecting system (one rapping mechanism for each section)
6. Collecting electrodes
7. Dust hopper (other types of discharge arrangements such as troughs and flat bottoms with scrapers are also available)
8. Dust-discharge opening
9. Heat insulation
10. Drive gear for the collecting system rapping mechanism (only one entry required for each section)
11. Insulated access door
12. Drive gear for the discharge-system rapping mechanism
13. Transformer rectifiers with constant current regulation
14. Insulator housing (electrically or hot air heated to prevent condensation on insulators)

General Description

Consists of a group of large segmented chambers, usually insulated. Suspended in each chamber are flat collecting plates with equal spacing and discharge electrodes (usually wires) between each set of plates. The discharge electrodes and collecting plates are electrically insulated from each other. Transition ducting leads the gas to and from the unit with dust being removed via the bottom.

Principle of Operation

Particles to be collected are electrically charged. This is accomplished by the attachment of negative ions and electrons which have been formed by the electrical ionization of gas close to a highly charged discharge wire. The electrical field established between the discharge electrode and a grounded plate draws the charged particle to the plate where it is deposited. The collected material is removed as an agglomerated mass from the collecting plates by mechanical rapping.

Materials of Construction

Temperature and corrosion resistance are the two most important factors in the selection of materials.

- Collecting surfaces - carbon steel, special high alloy steel, lead.
- Discharge electrodes - carbon steel, alloy steel.
- Shell - carbon steel, alloy steel, tile, fiberglass.
- Support members - carbon steel, alloy steel.

Advantages Over Other Types

- Low pressure drop.
- High removal efficiency for small particle size.
- Handles high temperature gases.
- Used for both solid and liquid particulate matter.

SIZING CRITERIA

- Plate spacing: 8-12 in.
- Velocity through precipitation: 2.95-5.91 ft/s.
- Vertical height of plates: 11.8-32.8 ft.
- Draft loss: 0.004-0.029 psi.
- Collection area: 4,300-10,765 ft^2.
- Efficiency: 93-99%.
- Migration velocity: 2.36-4.72 in/s.
- Fields: 1-4.

General Sizing Equation

$$E = 1-e^{\left(-w \frac{A}{\ }\right)}$$

E = collection efficiency.

w = drift velocity (ft/sec) = 0.2-0.33

A = plate area (ft^2)

Q = flow rate (ACFS)

ACCESSORY COMPONENTS

- Ash handling equipment.
- Ducting, dampers, stack, air-moving equipment for wet bottom - wastewater treatment equipment.

SUPPORT REQUIREMENTS

Personnel: Operating labor per shift = 0.5 - 2 man-hr
Maintenance labor per shift = 0.5 - 1 man-hr

Training: Operator training required - usually supplied by manufacturer and/or vendor.

Skills Required: General mechanical and electrical.

Inspections: 1 general inspection/8 hr of operation; 1 detailed inspection/1,000 - 2,000 hrs of operation.

Access: Access to collecting plates, insulators, rapping mechanism, voltage supply and dust removal systems needed.

Spare Parts: Discharge wires and hangers.

Permits: Air Pollution Control.

OPERATIONAL CONSIDERATIONS

General: Key problem areas - corrosion, rapper failure, dust removal, electrical shorts.

Installation: Close as possible to emission source.

Maintenance: Routine maintenance of rappers and dust removal equipment.

Controls: Automatic voltage/current/spark rate controls available.

Scheduling: Continuous operation.

Downtime: Units are constructed in sections for redundancy, thus total system downtime can be minimized.

SAFETY AND ENVIRONMENTAL CONSIDERATIONS

General: Protect maintenance personnel from electrical shock hazard by interlocking access doors to safety switches.

Fire Hazard: Cannot be used on flammable dusts or gases.

Explosion: Minimal.

General Environmental: Must dispose of collected material in an environmentally acceptable manner.

COST ANALYSIS

Prices for dry type (mechanical rapper or vibrator) precipitators are contained in the figure from page B-14. Prices are a function of net plate area, which can be calculated using the general sizing equation given above.

Life Cycle Analysis for Equipment; short = 5 yrs; average = 20 yrs; long = 40 yrs.

Total Capital Costs

- Total cost = purchased equipment cost + installation cost.
- Installation indirect costs = 0.67 x purchased equipment costs.
- Installation direct costs = 0.57 x purchased equipment costs.

Operating Cost Components

- Labor: see Support Requirements.
- Electrical power = 1.5 watts/ft^2.
- Waste disposal - as needed.

STATE-OF-THE-ART

R&D Needs: Adapting ESP's to wider variety of emission sources, minimizing reentrainment of dust.

Operating Systems: See entries under Successes.

Manufacturers:

- Western Precipitation.
- Research Cottrell.
- United States Air Filter Corporation.
- American Air Filter.

Risks: Must design system specific to site specific dust resistivity. Do not apply to explosive gases or flammable dusts.

History: Developed in early 20th Century by Lodge in England and Cottrell in the U.S. First successful application on sulfuric acid mist and later on a power plant and smelter. ESP's are primarily designed by empirical means as opposed to theoretical formulas. Detailed mathematical models have been recently developed to predict performance.

Successes: Successful installations on a number of industrial applications. Primarily coal-fired utility and industrial boilers, cement kilns, incinerators, kraft pulp mills and metallurgical operations. ESP's installed on municipal solid waste incinerators in Saugas, Massachusetts; Nashville, Tennessee; Norfolk, Virginia; Ogden, Utah; Washington, D.C.; Chicago, Illinois; Baltimore, Maryland; Philadelphia, Pennsylvania. (See below.)

Failures: Individual cases of ESP failure on incinerators are not known. However, failure can result from excessive corrosion, improper dust resistivity, inadequate collecting area, improper gas distribution, poorly designed rapping (either too frequent or too infrequent), or excessive gas velocity.

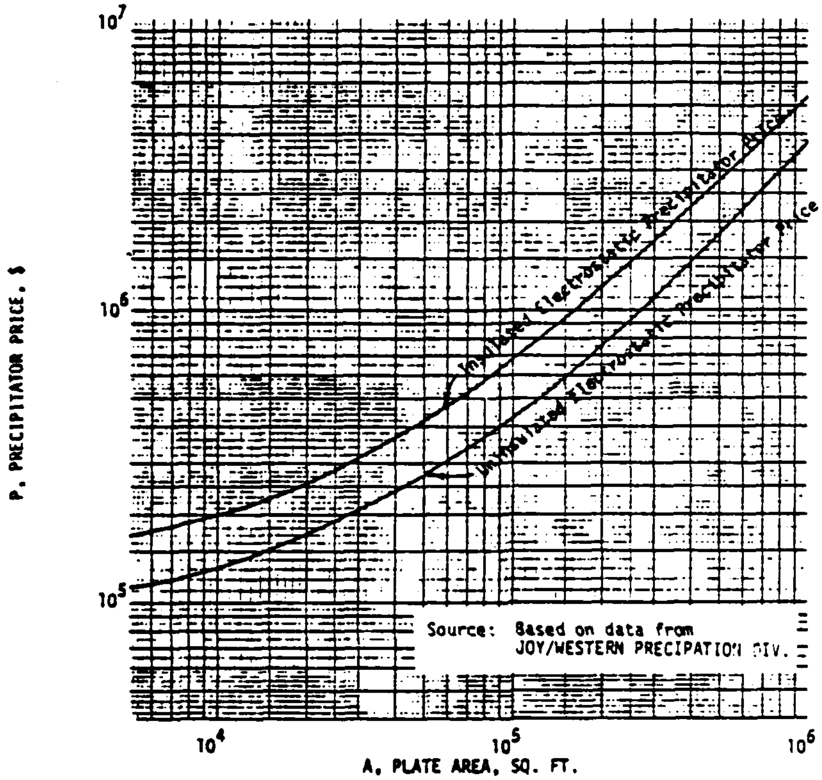
Key Problems: (See above.) Actual test results on existing and new municipal incinerator facilities indicate that the new source performance standard of 0.08 grains/DSCF is technologically feasible through the use of appropriately designed ESP.

Comments:

See References 1 and 2 for general ESP information.

REFERENCES

1. A Manual of ESP Technology, Oglesby, S., et al., NTIS No. PB-196 380, August 1970.
2. Industrial Electrostatic Precipitation, White, H.J., Addison-Wesley, 1963.
3. Inspection Manual for Enforcement of NSPS - Municipal Incinerators, U.S. EPA, 340/1-75-003, February 1975.
4. Capital and Operating Costs for Selected Air Pollution Control Systems, U.S. EPA 450/5-80-002, December 1978.
5. A Review of Standards of Performance for New Stationary Sources - Incinerators, EPA Contract 68-02-2526, March 1976 by the MITRE Corporation.



DRY TYPE ELECTROSTATIC PRECIPITATOR PURCHASE PRICES VS. PLATE AREA (4)

COMPONENT DESCRIPTION

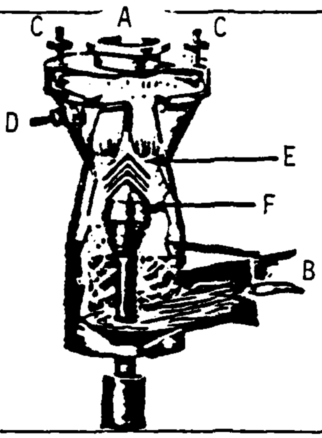
Types Available - Competing Components

a. Venturi
b. Flooded disc
c. Centrifugal
d. Spray towers
e. Moving bed
f. Plate
g. Packed bed

Type
Venturi

Types Used Commercially
Venturi

Physical Characteristics



A Gas with Pollutant Inlet
B Clean Gas to Demister (Used Separate Liquid from Gas Stream)
C Scrubber Wall Liquid Inlet
D Scrubber Liquid at Venturi Throat Inlet
E Venturi Throat
F Adjustable Construction to Increase

General Description

Scrubber utilizes moving gas stream to atomize liquid into drops, and then accelerates the drops to promote contact between particulate matter and liquid drops. Entrained liquid, captured particles, and gas flow to cyclonic dropout chamber (typically) where gas and liquid are separated.

Principle of Operation

Particulate removed from the gas by one of the following mechanisms:

- Inertial impaction (direct droplet/particle contact).
- Interception (indirect or close contact of liquid and solid).
- Diffusion (intersection of liquid and submicron particles due to Brownian motion).
- Electrostatic (attraction between liquid and solids).

Materials of Construction

Scrubber body	1/8 to 1/2 in. carbon steel plate -- noncorrosive 1/8 to 1/2 in. 316 or 304 stainless steel or 3/16 soft rubber lining (SRL) corrosive
Piping	FRP, SRL, carbon steel
Ducts & stack	Ceramic, brick or other noncorrosive

Advantages Over Other Types

Capability to remove submicron particles and operates at a h[illegible]r overall removal efficiency -- can be used to remove gas phase pollutants as well as particulate.

AIR POLLUTION CONTROL	Venturi Scrubber	APC-D	P. 2 of 4

SIZING CRITERIA

Gas velocity	20 to 40 fps
Pressure (flange to flange)	0.2-3.0 psi
Liquid rate	.005 gal/cu-ft of gas

ACCESSORY COMPONENTS

- Ducting, dampers, stack, air moving equipment.
- High efficiency demister.
- May require wastewater treatment including solids concentration/removal, flocculation, and neutralization.

SUPPORT REQUIREMENTS

Personnel: Operating labor -- 2 to 8 man-hr/shift, maintenance 1 to 2 man-hr/shift.

Training: Operator training required -- supplied by vendor.

Skill required: Electrical and mechanical.

Inspections: Daily operability inspections -- internal inspections/1,000 to 3,000 hr of operation.

Access: To adjustable venturi throat and demister internals.

Spare Parts: Pumps, pH controller, nozzles.

Permits: Air pollution control district.

OPERATIONAL CONSIDERATIONS

General: Primary problem areas

- plugging
- chemical or impact scale
- corrosion (requirement adequate pH control)

Installation: Proximity of the stack.

Maintenance: Routine inspection.

Controls: pH for corrosion - pressure for plugging or scaling.

Scheduling: Continuous

Downtime: Normal maintenance.

Other Factors: N/A.

SAFETY AND ENVIRONMENTAL CONSIDERATIONS

General: Key interlock or equivalent to prevent opening access doors while system is operating.

Fire Hazardous: Loss of scrubbing liquor supply should be coupled to system shutdown - protects scrubber lining (FRP and rubber) and other internals from high temperatures.
Explosion: Minimal.

Other Safety: N/A.

General Environmental: Scurbber effluent may require treatment. Gases discharged will be saturated with water: dense white plume may occur at gound level. Reheat may be required.

COST ANALYSIS

Capital cost = 7117 + 408 - $0.35v^2$ where:
v= 1,000 acfm, 1/8 in. carbon steel
<20,000 acfm, flange to flange, pump, control demister

Economic Life Factors

- Low -- 5 years.
- Average -- 10 years.
- High -- 20 years.

Capital Costs

Installation: (0.56) x (capital cost)

Indirect: (0.35) x (capital cost)

Operating Costs

Power to overcome P and LG ratio
E = $0.0432/KWh and KWh = (0.746) (horsepower) (hours of operation)
Horsepower = pump + fan horsepower

STATE-OF-THE-ART

R&D Needs: Present activities include the development of flux-force/condensation and electrostatically aided-scrubbers.

Operating System: Virtually every industry which requires particulate matter control.

Manufacturers: American Air Filter, Artisan Ind. Inc., Badcock & Wilcox Company, Beltran Associates, Croll-Reynolds Company, Feeco International, Graham Manufacturing Company, Jones & Hunt, MHI, Zurn.

Risks: N/A.

Other Information: N/A.

AIR POLLUTION CONTROL	Venturi Scrubber	APC-D	P. 4 of 4

History: Commercially available since 1947, principals of operation known since about 1900.

Successes: Venturi scrubber operation at 15-20 in W.G. were successful in reaching 0.08 grains/DSCFM at 12 percent CO_2 level. Applications to coal-fired boilers - efficiencies of 96 percent at P - 20 in W. G. have been experienced.

Failures: Carry-over of scrubber solids and inefficient demister operation reduce collection efficiency. Corrosion of internal components leads to greatest failure rate.

Key Problems: Corrosion of scrubber internals, downstream ducts and stacks and poor demister operation.

Comments -- Additional Data

a. Venturi most often used and is applicable for high efficiency particulate control to meet NSPS.
b. References

REFERENCES: SEE C(30) FOR ADDITIONAL REFERENCES

1. Capital and Operating Costs of Selected Air Pollution Control Systems EPA 450/5-80-002, GARD, Inc.
2. A Review of Standards of Performance for New Stationary Sources - Incinerators - The Mitre Corporation MTR-7983.
3. Inspection Manual for Enforcement of NSPS - EPA 340/1-75-003.
4. Performance of Emission Control Devices On Boilers Firing Municipal Solid Wastes and Oil - EPA 600/2-76-209.
5. Calvert, et al., Wet Scrubber System Study Volumes 1 & 2, EPA-RZ72-118a & b.
6. Calvert, et al. Fine particulate Scrubber Performance Tests. EPA-650/2-74-093.
7. Stern, A.C. (ed.) Air Pollution, Volume IV. Third Edition. Academic Press, N.Y., 1977.

APPENDIX C

COMBUSTION EQUIPMENT (CE)

COMBUSTION EQUIPMENT	Modular Incinerator	CE-A	P. 1 of 6

COMPONENT DESCRIPTION

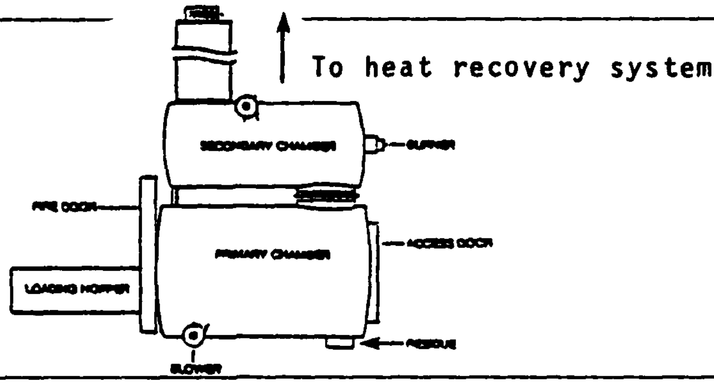
Heat Recovery Incinerator

Type
Controlled-Air

Types Available
- A. Rotary kiln
- B. Stationary grate
- C. Auger bed

Types Used Commercially
A,B

Physical Characteristics



General Description

Modular incineration systems typically contain multiple factory constructed units of identical design; hence the term modular. The units are designed to operate independently, however in systems where steam or hot water production is designed the multiple units will typically use a common boiler.

Controlled air incinerators which operate with less air than that required for complete combustion (usually 30 to 40%) are called starved air or substoichiometric air incinerators. These units are also referred to as pyrolytic incinerators. This terminology however is incorrect, as the combustion process which takes place does not meet the high temperature, low air requirements of pyrolysis.

Systems which provide more than the minimum quantity of combustion air are known as excess air incinerators. The air flow into these systems is also controlled as in a starved air system.

The above terminology refers to the primary combustion chambers only. In all systems the secondary chamber is supplied with between 100 and 150% of theoretical air requirements to complete oxidation of the primary combustion products.

Feed mechanisms, materials of construction, ash handling systems and controls will vary with the manufacturer. There are numerous methods of specifying each. Typical arrangements employ a hopper and hydraulically driven ram as feed mechanisms; heavy steel and cast refractory construction; automatic water quench tank for ash handling; and semiautomatic control.

Combustion grate arrangement also varies with the manufacturer. Stationary, reciprocating, and rotary grates are all available. Data are not available to determine if a particular grate arrangement is superior to others.

Principle of Operation

Raw waste is delivered to the incinerator facility and deposited onto a tipping floor or into a pit. Oversized or otherwise unprocessible items are removed and disposed of. The waste is fed into the primary chamber in controlled batches. The batch size, usually between one and four cubic yards, varies with the waste characteristics, particularly particle size, bulk density and Btu content, as well as with the incinerator capacity.

Ongoing combustion within the primary chamber successively dries, volitalizes and then combusts the waste. During initial start-up operations auxillary burners are used to bring the unit to temperature.

Partially combusted gases and particulates are drawn up into the secondary chamber where additional quantities of air is injected. In some designs the high gas temperature alone is sufficient to ignite the mixture. When this ignition mechanism is not adequate auxillary fuel burners serve that purpose. Controlled air combustion in the two chambers burns virtually all the combustible gases and particulates. However the stack emissions can contain some unburned carbon, as well as inert particles and vapors. In some installations, particularly larger municipal systems (50 tpd or greater), additional stack gas cleaning devices such as electrostatic precipitators are needed to meet federal, state, and local pollution standards.

Systems which incorporate heat recovery, do so by installing either a water tube or fire tube boiler downstream of the secondary chamber. Gas temperatures entering the boiler are generally between 1,000 and 1,800°F while exit temperatures are approximately 350°F.

Ash and other incombustible residue which settle on the hearth of the primary chamber after the combustion process must be periodically removed. In the manual system, the operator must scoop out the ash (by shovel or front-end loader) after the unit has been shut off and cooled down. The ash in an automatic system is pushed or forced ahead of the burning waste until it exits the chamber, into either a water-sealed pit or an air lock chamber.

Advantages over other types

Substoichiometrically-controlled air incinerators have as an inherent advantage, the reduced air pollution control equipment requirements and blower horsepower requirements resulting from the reduced quantities of combustion gases used in the process.

SIZING CRITERIA

Item	Length (ft)	Width (ft)	Height (ft)
Delivery door	NA	20	24
Ram feed hopper (feed door elevated)	20	7	12
Primary combustion chamber	20	12	11
Secondary combustion chamber*	20	10	10
Boiler (15,000 lb/hr [6804 kg/hr] capacity**)	26	10	11

Ash quench and conveyor removal	20	8	6
Tipping floor	varies with holding capacity		

Basis: Piggyback configuration,
1 ton/hr capacity

* Secondary chamber elevated above primary chamber.

** Boiler can be elevated above ash removal area at secondary chamber level.
(Metric Conversion Factor: 1 ft = 0.3 m)

ACCESSORY COMPONENTS

Item	Reference No.
Weight station (optional)	Not included
Tipping area	Not included
Boiler feedwater treatment	Not included
Bulky combustible shredder (optional)	MH-F, MH-g
Steam distribution/condensate return line	Not included
Back up boiler (optional)	Not included

SUPPORT REQUIREMENTS

Personnel: Per shift personnel required are: front-end loader operator, incinerator operator, laborer, mechanic, supervisor. Additional requirements may include: 1 clerk, 1 electrician, and a boiler operator.

Training: Training of operators, supervisors, and backup personnel should begin when the project is in the initial stages and continue through the time that the system is on-line. Total personnel time required for training averages 1 mo/person.

Skills Required: Skill requirement will vary with assignment. Highly skilled positions include: incinerator operator, mechanic, and boiler operation and experience contributes significantly to successful overall incinerator plant operation.

Inspections: All equipment should be routinely inspected to assure steady operation and to minimize lengthy down-time. A facility can expect periodic inspections from both Navy and civilian regulatory agencies.

Access: The facility should be located reasonably close to both waste generation areas and more critically to energy markets. Building must be accessible to the collection vehicles employed. Each piece of equipment should be easily accessible for maintenance purposes.

Spare parts: Recommended spare parts include hydraulic cylinders, fan motors, bearings, seals, timers, and other control mechanisms. Most major pieces of equipment have redundant companions to assure against lengthy down time. Refractory can usually be purchased locally, where this is not possible, spare refractory should be stored.

Permits: Stationary source air pollution control permits will be required for all facilities. Compliance tests are required for air pollutant emissions. Local or state pollution control agencies can usually provide information about what types of compliance tests are necessary. A formal environmental impact assessment (EIA) or, in many cases, a formal environmental impact statement (EIS) will be required for a heat-recovery incinerator plant.

OPERATIONAL CONSIDERATIONS

General: There is a degree of uncertainty and risk regarding the performance of the controlled-air system and its life cycle costs and benefits. This uncertainty is due to its brief history of operation, insufficient instrumentation and record-keeping at operating facilities, and/or industry tendency to market equipment before completing investigative and developmental work.

Installation: Installation will include site preparation, building construction and support facilities. These items can be constructed in the interim between purchase and delivery of the incinerator units.

Maintenance: Routine maintenance along with operator training are the most important components of a successful operation. Lack of maintenance has caused a number of incineration facilities to burn-out and subsequently be dismantled.

Controls: Controlled-air systems should be accompanied by thorough instrumentation and performance monitoring, to collect performance and cost data for use in project development and evaluation.

Scheduling: Start-up and shake-down periods of upwards of 1/2 - 2 years have been noted. Once in continuous operation operating systems experience only routine scheduled down-time. Most facilities are designed to operate 24 hours per day, 5 days per week.

SAFETY AND ENVIRONMENTAL CONSIDERATIONS

General: Plant design should include facilities for personnel hygiene, meals, and meetings for working personnel. A program of safety inspection and training should be a normal part of plant operation. Minimum requirements for ventilation and illumination should be met or exceeded. General safety equipment such as first aid kits, fire extinguishers, hoses, intercom, handlights, and equipment-related devices should be furnished. Employee safety equipment (hard hats, masks, goggles, protective clothing, safety shoes, fire blankets, cots, and stretchers) should be provided.

Fire Hazard: Fire danger is low provided recommended operating procedures and housekeeping requirements are followed.

Explosions: Explosion hazard is low. Any explosion which occurs within the primary chamber should be contained within.

Other Safety: Incinerator and boiler walls and steam lines can become hot. Adequate protection and warnings should be installed.

General Env.: Modular incinerators typically emit particulates with concentrations of less than 0.2 gr/scf (12% CO_2). Federal New Source Performance Standards (Subpart E) set a particulate emission level of 0.08 gr/scf (12% CO_2) on units of 50 ton per day or greater. State and local standards for units of lesser capacity will vary but will generally be lower. Therefore, some pollution control device may be necessary. Manufacturers typically supply systems which incorporate adequate control devices.

Cost Analysis

Incinerator systems are capital intensive projects. Variations in costs between manufacturers should be considered. However, due to limited data, only operating and labor costs from systems suppliers was included (see graph on p. 6).

Life Cycle Analysis: Available data is not sufficient to determine true life cycle cost of modular incinerators.

STATE-OF-THE-ART

R&D Needs: Careful monitoring of operating facilities is needed to accurately determine system performance, cost, and maintenance requirements.

Operating Systems: There are at least 12 operating municipal heat recovery modular units in the United States. Additional facilities are in start-up or an advanced design stages.

Manufacturers: At least 20 companies manufacture modular incinerators. A partial listing of manufacturers is included under Comments Section.

Risks: Risks involving potentially changing waste characteristics, unknown reliability of major equipment, possible changes in demand for product steam and limitations on ash disposal.

Other Information:

History: Controlled-air incinerators first became commercially available in the late 1960's. Initial designs did not include heat recovery. Prior to the introduction of controlled-air units practically all incinerators were uncontrolled excess air units.

Successess: Reliable heat recovery from modular incineration has been demonstrated. Of particular interest is the 50 tpd system in Osceola, Arkansas. The facility has operated 24 hours per day 5 days per week with only 2 unscheduled days of down-time. The facility routinely produces 8,000 lb/hr of 125°F saturated steam. However, the system was installed in early 1980 and has not been forced into the refractory replacement typical of 4-5 year old systems.

Failures: There have been numerous cases where complete systems have failed and have been dismantled. The communities of Augusta, Truman, and Siloam Springs, Arkansas, all have inactive systems. The 100 tpd facility in North Little Rock, Arkansas, for years a show case facility, is now operating at one-half capacity due to lack of adequate maintenance and an over estimation of the Btu content of the waste stream.

Key Problems:

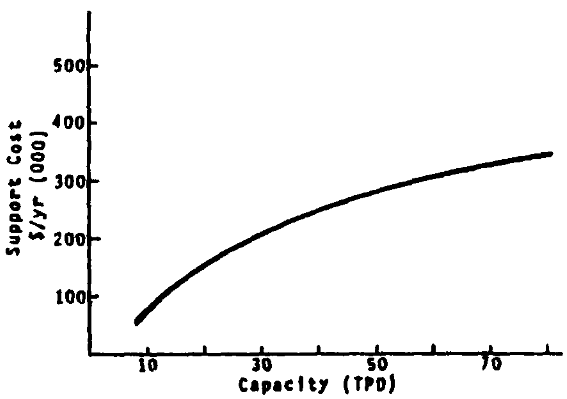
- Lack of adequate maintenance.
- Over estimating Btu content of waste stream.
- Over estimation of capturable waste quantity.
- Manufacturers selling systems prior to complete understanding of operational parameters.

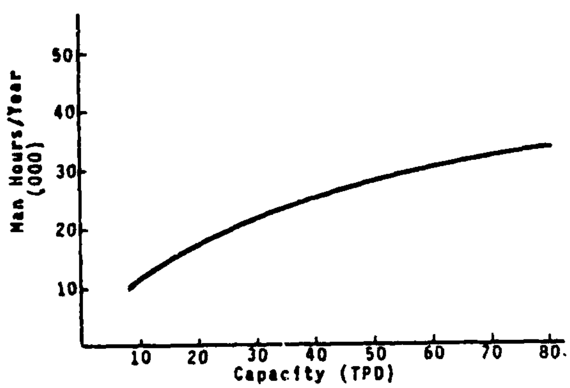
- Unreliable operation.
- Non-redundant designs have caused entire plants to shut down for repair of a single item.

Comments

Partial list of modular incinerator manufacturers:

- Basic Environmental Engineering, Glen Ellyn, IL.
- Burn-Zol, Dover, NJ.
- C.E. Bartlett-Snow, Chicago, IL.
- Clean Air, Inc., Ogden, Ut.
- Comtro Division, Meadville, PA.
- Consumat, Richmond, VA.
- Environmental Control Products, Charlotte, NC.
- Kelley Company, Inc., Milwaukee, WA.
- Lamb-Cargate, New Westminster, B.C., Canada.
- Morse-Boulger, Corona, NY.
- Simonds Company, Winter Haven, FL.





COMPONENT DESCRIPTION

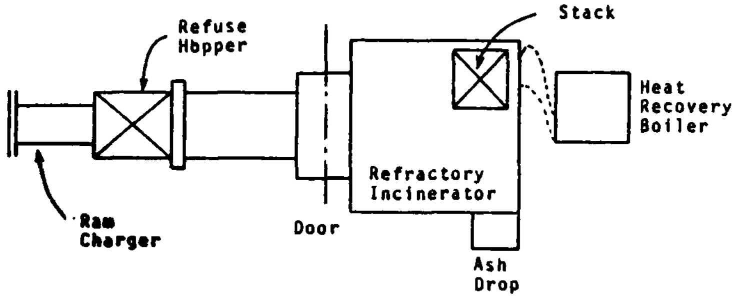
Refractory Wall Heat Recovery Incinerator

Type
Refractory Wall

Types Available - Competing Components
a. Solid unprocessed
b. Liquid
c. Sludge
d. Co-firing
e. Pathological

Types Used Commercially
a, b, c, d, e

Physical Characteristics



General Description

The heat recovery refractory-lined incinerator has refractory lining in the combustion chamber where as-discarded solid waste is combusted over air-cooled traveling or stoker grate. Final hot gases are directed to a heat recovery boiler and then to a pollution control device. Some modular incinerators work as controlled-air units. Excess air is generally 100-300% to keep the refractory cool, and to avoid slagging. The units are provided with manual or continuous ash dumping systems. In some instances, with high moisture content refuse auxiliary fuel is needed for startup or continued incineration.

Principle of Operation

Field-erected units are of Dutch-oven design. Gasification occurs in the Dutch oven section and combustion of the volatile combustibles occurs in the baffled zone after turbulent mixing with air. In modular units, vaporization occurs in the primary chamber by exchanging heat between hot refractory wall and ceiling and refuse. The combustible gases are combusted in the refractory line secondary combustion chamber. Wide variety of refuse could be accepted in such incinerators. Modular systems are addressed elsewhere in this document. For batch and intermittent operations, the refractory walls should be kept hot during downtimes. High excess air use makes the incinerator less efficient in heat recovery. Field-erected units are generally over 100 tpd capacity. Such units normally require costly pollution control equipment systems.

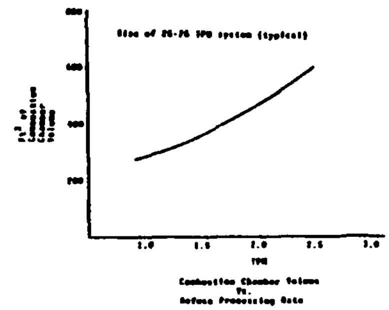
Materials of Construction

1. Casing refractory: Hot Roll steel - ASTM-A-30-10GA or better.
2. Refractory-alumina bricks or castables and fire bricks at the face of the casing.
3. Grate: Cast iron (fixed grate) or formed steel (travelling).

Advantages Over Other Types

- Less costly, i.e., $/ton of investment capital is low.
- Relatively simple operating procedure.
- Moderate operating costs.
- Many manufacturers in the market, so competitive pricing possible.
- Waste heat recovery possible by using a waste heat boiler.

SIZING CRITERIA



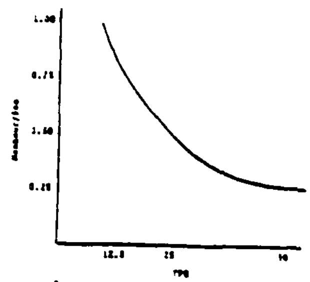
- Quantity of refuse to be disposed/hr or day.
- Average heating value of refuse to be disposed.
- Physical characteristics of refuse.
- Energy recovery at 3 lb/lb of refuse (as discarded).

ACCESSORY COMPONENTS

- Automatic ram feeds.
- Automatic ash/residue removal.
- Automatic auxiliary burner control.
- Automatic combustion air control.

SUPPORT REQUIREMENTS

Personnel: 5-10 tpd operation 1/shift, 11-50 tpd operation 2/shift, 50-200 tpd operation 3/shift Plus administrative and maintenance crew in 1st shift.

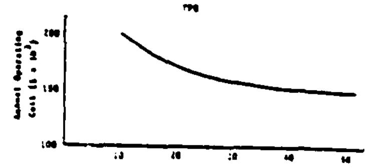


Training: Operators - 2 weeks necessary/operator.

Skills Required: Mechanically oriented, hard labor class.

Inspections:

- Refractory lining.
- Pollution controller.
- Grate plugging with slag and debris.
- Feeder wear and fume leakage.



Access: 10 ft to 15 ft on all sides for maintenance work. 20 ft in the front for feeder pull out.

Spare Parts: All drive components, refractory bricks and cements.

Permits: Environmental impact, health and air pollution permit, zoning.

OPERATIONAL CONSIDERATIONS

General: For continuous operation, 2 days storage of refuse; for batch operation dispose as it comes. For weekend operation and no-delivery, storage space for burning refuse during nondelivery hours needed.

Installation: Close to waste producer.

Maintenance: Routine and weekend refractory patch-up work.

Controls: Combustion system: automated, others: semi-auto, with manual override.

Scheduling: For batch operation - operate as needed. Keep refractory hearth hot.

Downtime: Only when needed to repair refractory or grate.
Other Factors: Close watch should be kept on furnace wall and shell. Discoloration of shell indicates refractory wear and hot-flash to steel casing.

SAFETY AND ENVIRONMENTAL CONSIDERATIONS

General: Should not be located in congested neighborhood, good access for refuse trucks, ambulance, and firetrucks.

Fire Hazard: Good housekeeping, fire hose near furnace and loading zones. Sprinkler system in building.

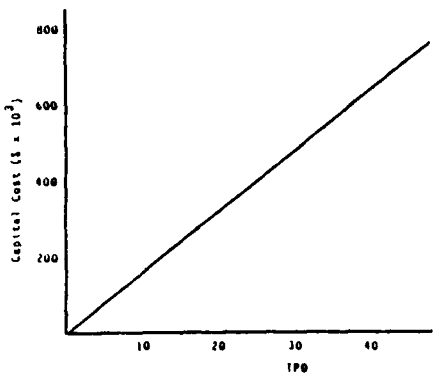
Explosion: Aerosol and other explosive materials should be avoided.

Other Safety: Automatic shutoff for combustion air and auxiliary fuel if any. Overload protection for grate drive motor. Over-temperature alarm for combustion chamber.

COST ANALYSIS

Capital cost of field-erected refractory lined heat recovery incinerator depends upon the equipment system, location, wage rate, transportation costs and other factors. Vendors refuse to quote ball-park cost data.

Operating and maintenance costs: labor costs depend upon type of facility, hours of operation, and local labor rates. For safety reasons, a minimum of 2 men/shift is required for municipal and 1 man/shift for industrial installations. Auxiliary fuel cost depends upon the type of refuse and shutdown. Schedules average auxiliary fuel consumption: 1 MCF/tpd.



Life Cycle Cost Analysis:

Electric power cost = 0.5 KW/tpd

Water use = 2 gal/ton for ash quench + 3 gal/ton for other uses

Maintenance labor 2 percent of plant facilities investment (pfi) capital cost

Maintenance supplies = 2% of pfi

STATE-OF-THE-ART

R&D Needs: Refractory incinerators are old technology. Many have been working successfully for years.

Operating Systems: Most of the units are provided with waste heat boilers (field-erected units)

Manufacturers: Basic, Consumat, Air-Preheat, Kelley

Risks: Heavy refractory maintenance for batch operations. Air quality degradation if operated without appropriate air pollution controls.

History: Non-energy recovery incinerators have refractory combustion chambers. The choice between burning refuse in refractory incinerators or providing for energy recovery is not clear cut. Many industrial and commercial wastes are combusted in refractory-lined incinerators with heat recovery. Heat recovery in refractory incinerators are coming into focus because of energy crisis. It has low capital cost but high maintenance cost.

Successes: Many refractory-lined municipal incinerators have been running for years without major failures. The use of silicon carbide or high alumina bricks give long refractory life. It is widely used in hospitals, shopping centers and in many commercial facilities with remarkable success.

Failures: Most of the failures have been due to poor maintenance of the refractory.

Key Problems: Slagging and short life of the refractory. Incinerators with waste heat boilers experience tube corrosion and erosion of refractories and grate plugging problems. Air-cooled refractory has solved many of the ills of short-life refractory linings.

Furnace Wall: To reduce slagging to a minimum and extend furnace life, silicon carbide face brick with air-cooled walls are recommended. The silicon carbide refractory extends from the grate line to approximately 6 ft above grate.

Instrumentation and controls:

- Overfire air, wall cooling air and the underfire air.
- Gas temperature in the furnace, inlet to the settling chambers.
- Draft control.
- Refractory wall temperature.
- Under grate air control.

Field-erected refractory incinerators are generally 200 tpd and above [illegible] units of 50 tpd, modular shop-assembled units are available.

REFERENCES

1. Proceedings of Mecar symposium - Incineration of Soli[illegible]
2. Small Modular Incinerator Systems With Heat Recovery - [illegible] and Economic Evaluation - EPA, SW-177C, November [illegible].
3. Weinstein and Toro, Thermal Processing of MSW [illegible] Science, Publishers, Inc.
4. G. Tchobanoglous, Thirsen, and Flassen, [illegible]
5. Personal communications with Basic Env[illegible]
6. Small-Scaled Low Tech., Resource Re[illegible] Engineers.

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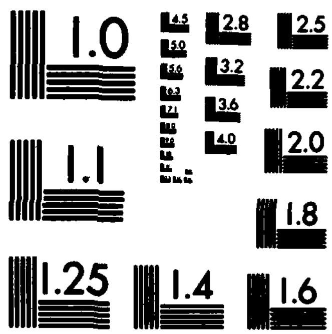


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

COMBUSTION EQUIPMENT	Heat Recovery Incinerator	CE-C	P. 1 of 5

COMPONENT DESCRIPTION

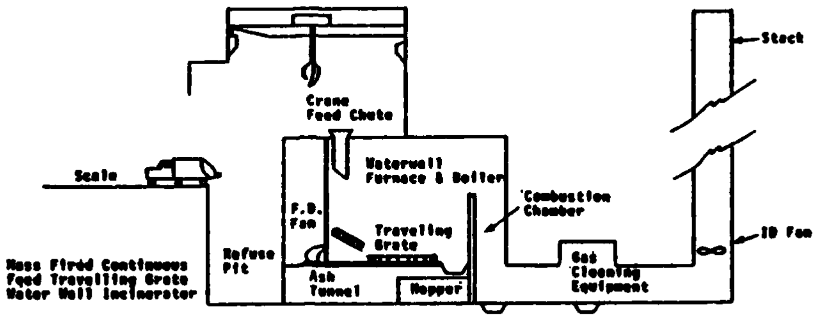
Shop-assembled or site-erected

Type
Watertube wall

Types Available - Competing Components
- a. Solid unprocessed
- b. Solid processed
- c. Liquid burning
- d. Sludge burning
- e. Co-firing

Types Used Commercially
a, b, c, d, e

Physical Characteristics



General Description

In watertube wall incinerators, the walls of the combustion chamber are lined with boiler tubes that are arranged vertically and welded together in continuous sections. The tubes are insulated on the outside to reduce radiant heat losses. Such incinerators can accept processed or unprocessed wastes. Depending on the degree of processing, mass, suspension or vortex firing can be achieved. For mass burning, reciprocating, traveling, or barrel grates are used to convey solid wastes through furnace.

Principle of Operation

In water wall incinerators, water circulates through the tubes that form the walls of the furnace, and absorbs heat generated in the combustion chamber. The heated water is used to produce steam. When water walls are used in place of refractory materials, they are not only useful for the recovery of steam, but also extremely effective in controlling furnace temperature without introducing excess air. This reduces flue gas quantity (30-40% over refractory furnace) and smaller pollution control equipment is therefore needed.

Materials of Construction

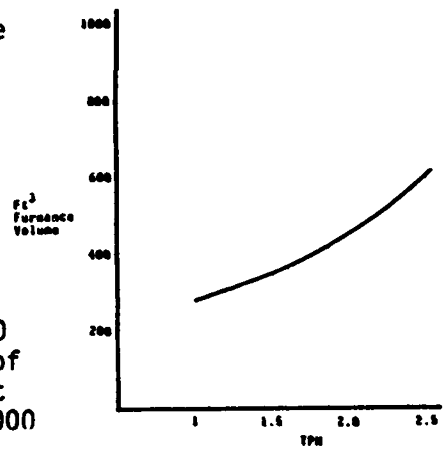
1. Steam drums: SA-285.
2. Firebox: SA-515.
3. Waterwall tubes: SA-192, 210, 213,
4. Furnace wall and economizer: Hot-rolled, low-carbon seamless, or electric - resistance welding tubes.

Advantages Over Other Types

- Excess air requirements are usually on the order of 40-80% as compared to 100-200% often used in refractory furnaces.
- Can be co-fired with coal or sludge.
- Smaller pollution control and air-handling equipment system.
- Lower maintenance.
- High heat release rates per unit volume of furnace.

SIZING CRITERIA

Physical and chemical characteristics of refuse and feed rate are the two important sizing criteria. The capacity utilization factor of a given water wall incinerator will depend upon type of refuse, its heating value, (moisture, ratio of combustibles to noncombustibles) and maximum charging rate. Average steam producing capacity of a pound of refuse is 3 pounds of steam. However, steam generating capacity control vary from 1.3 to 4.3 lbs steam/lb refuse.



Water wall incinerator sizes will depend upon refuse type, firing device and throughput rate. Size of 250 tpd to 400 tpd is typical. Water wall incinerators of <1 to 3 tph capacity are not too prevalent. The heat release rate per unit furnace volume ranges from 25,000 to 40,000 Btu/ft^3.

ACCESSORY COMPONENTS

- Truck scales.
- Storage pit.
- Feeding crane.
- Front-end processing equipment (if suspension or vortex firing).
- Stoker: traveling, reciprocating, or reverse stroking type, and rocking grate.
- Pollution control equipment.
- Waste heat boiler and accessories.
- Ash-handling and residue-handling systems.

SUPPORT REQUIREMENTS

Personnel: 12.5 tpd - 1.0 man-hr/ton
25.0 tpd - 0.5 man-hr/ton
50.0 tpd - 0.25 man-hr/ton

Training: 3 months on job training, 1 year or more plant running responsibilities.

Skills Required: Boiler operator, electrical and piping technicians, instrumentation and control person.

Inspections: Annual - boiler watertube surface. Half-yearly firing and feeding system and controls.

Access: 15 ft 0 in on all sides tube removal space.

Spare Parts: On major components.

Permits: Air pollution control and environmental impact.

OPERATIONAL CONSIDERATIONS

General: Refuse feed rate proportional to steam production desired.

Installation: Close to steam user.

Maintenance: Routine daily maintenance.

Controls: Boiler - automatic with manual override.

Scheduling: Refuse storage at least 2 days operation load.

Downtime: Minimum, unless absolutely necessary.

Other Factors: Pollution control equipment and feedwater system should be maintained regularly.

SAFETY AND ENVIRONMENTAL CONSIDERATIONS

General: Installation in open area away from congested neighborhood. Good access road for refuse trucks, ambulance, and fire trucks.

Fire Hazard: Refuse storage area ventilated with exhaust fan and provided with sprinkler system and provision for fire hose.

Explosion: If processing required, dust explosion possible and provision for preventing such explosion should be made. Explosive materials, like gas tanks, or pressured containers, should be pre-sorted.

Other Safety: First aid station, safety shower, and general good housekeeping is required.

General Environmental: Air, water, and land environment, and aesthetic appearance of processing station should be maintained.

COST ANALYSIS

The variables that affect the operating cost are: the capacity of the unit, the percentage of capacity at which the system is operated, and the percentage of operating time per year. Typical operating cost of a 50 tpd unit is labor = $6.03/ton, utilities = $2.13/ton and maintenance = $1.07/ton. Administration costs are extra. (See graphs on page C-15).

Life Cycle Analysis consists of analyzed capital cost and operating cost. Annualized capital cost is calculated as: plant investment cost x CRF/365 x tpd x utilization factor.

CRF for 20-yr life at 10% ≈ 0.11746, utilization factor may be assumed = 0.7. Total operating cost (capital + operating) $12.50 to $16.50/ton.

STATE-OF-THE-ART

R&D Needs: Water wall incineration process is a fully developed commercial technology. R&D work should be in the field of boiler tube corrosion, ash-handling, and slagging problems.

Operating Systems: Most operating systems produce saturated steam 150-1,500 psig.

Manufacturers: B&W, and other custom incinerator mfgrs.

Risks: Boiler tube failure, air pollution with particulates and acid fumes.

History: While common in Europe, the conversion of solid waste to energy in the United States was, until recently, only an interesting idea. Recent energy crises have drawn more than 20 cities to start projects for steam and power generation from MSW. U.S. EPA has spent a great deal of effort and money in promoting this concept of energy recovery.

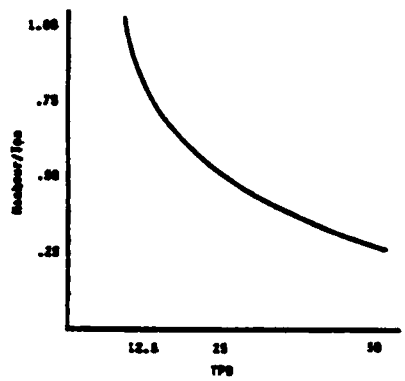
Successes: Several successful large-scale water wall type incinerators are now in operation (i.e., Sangus, Chicago Northwest, Harrisburg, PA.; Nashville TN; Hamilton, Ontario; Montreal, Canada; Quebec, Canada; and many smaller installations are operating now in the United States, Canada, and Europe).

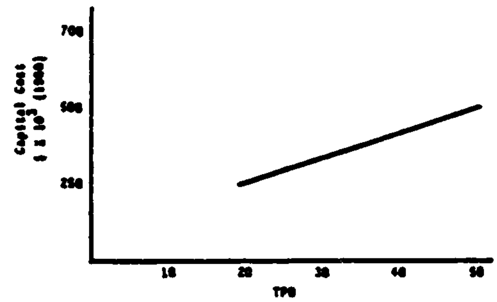
Failures: Slagging, acid corrosion, and fly ash erosion of the water wall tubes are the main causes of failure. Air pollution associated with particulates and acid fumes and pollution associated with MSW feeding have caused many shutdowns.

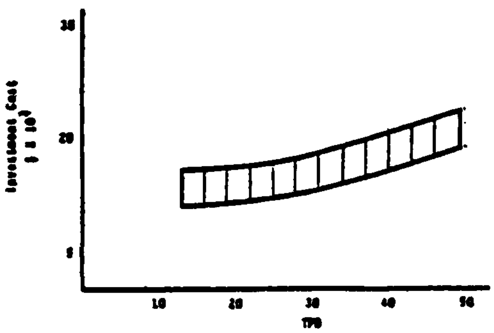
Key Problems: Arises from mixing of household refuse with commercial (i.e., industrial and building demolition wastes). Incineration of processed wastes have problems associated with feeding, ash-handling, and pollution control.

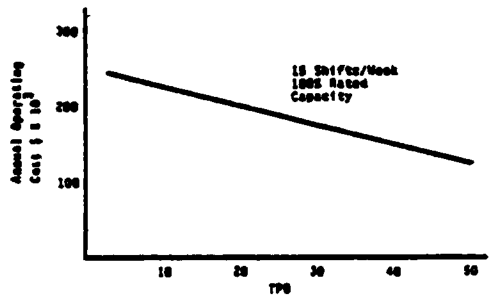
REFERENCES

1. J. Jones, et al., Appendix A, Mass Burning of Refuse in Shop Fabrication Incinerators. SRI International, Prepared for U.S. Navy, CEL, October 1979.
2. Small modular incinerators systems with heat recovery - EPA Publication SW-177C, November 1979.


1.00
.75
.50
.25
12.5
25
50
TPD


700
500
250
10
20
30
40
50
TPD


Investment Cost
35
20
5
10
20
30
40
50
TPD


Annual Operating
300
200
100
15 Shifts/Week
100% Rated
Capacity
10
20
30
40
50
TPD

COMPONENT DESCRIPTION

Heat Recovery Boiler

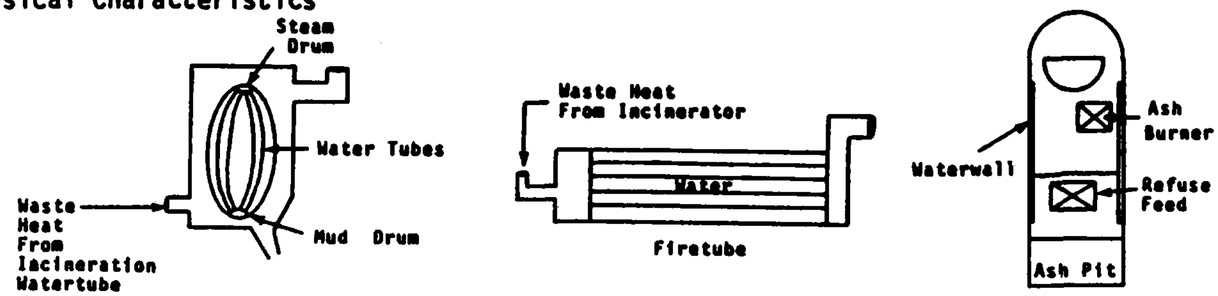
Type
Firetube & Watertube

Types Available
- a. Solid waste burning
- b. Waste heat boiler
- c. Hot water
- d. Steam
- e. Firetube
- f. Watertube

Types Used Commercially
Modular - firetube & watertube
Site erect - watertube

Physical Characteristics

Heat Recovery Boiler



General Description

Heat recovery boiler can be of firetube or watertube variety. Small modular units are generally of firetube variety. The boiler may be designed to receive hot products of combustion from a refuse burning incinerator or refuse can directly be fired in the boiler combustion chamber as a fuel. For watertube boiler, a portion (35 to 50%) of the heat produced in the combustion chamber of an incinerator, can be harnessed by a water wall either surrounding the combustion chamber or inbedded in the refractory wall. For waste heat boiler, the incinerator serves as the combustion chamber. For integral type boiler, the boiler heat transfer sections (convection and radiation) forms an envelope surrounding the boilers combustion chamber.

Principle of Operation

In firetube boiler, flue tubes are immersed into a water bath. The combustion flame travels through the flue tubes, and transfers heat to the water surrounding the tubes. Firetube boilers are slow to produce steam but contains a large reservoir of heat.

For watertube boiler, water circulates through the tubes, receives heat by convection and radiation from the flames and hct products of combustion. The heat transfer is from hot combustion product to the watertube by convection and radiation and from watertube to water by conduction and convection. The watertube boiler has the capacity to produce steam within short time of firing. The water circulating through the tubes needs to be conditioned and treated to avoid scale formation and consequent failure of tubes. Normally, most of the field-erected units (large) are of watertube variety.

Materials of Construction

Boilers are normally manufactured by ASME Boiler and Pressure Vessel Code, Section 1, Power Boilers, June 30, 1970, and subsequent addenda. Steam drums are normally LSA-285, A, B, or C grade carbon steel. Fiberbox quality plate is used for any part of a boiler subjected to pressure and exposed to the fire or hot products of combustion. For such use SA-515 grade 70 is used. In writing boiler specification, "ASME approved stamp is required," should be incorporated. This stamp can only be put on the boiler when the boiler has been constructed in accordance with the appropriate ASME boiler code.

Advantages Over Other Types

Firetube boiler - generally, shop assembled, modular unit, and cheaper than watertube boiler. Has low thermal efficiency.

Watertube boiler - higher thermal efficiency and more costly than firetube boiler. They are more complicated and required higher maintenance than firetube boilers. They have a quick response to steam-load and can be built to large steam producing capacities.

SIZING CRITERIA

- Btu/hr input to the boiler. Typically efficiency is 65 - 72%.
- Waste flow rate to the boiler.

Size of Boilers (typical) (See graph on Page 5.)

- Fire boiler - 5,000 to 25,000 lb/hr
- Watertube boiler - 25,000 lb/hr steam to above capacity

ACCESSORY COMPONENTS

For waste heat boiler - water tube variety:

- Water treatment facility.
- Condensate return system
- Pollution control device.
- Boiler automatic control system.
- Soot-blowing system.

For directly-fired incinerator - boiler system:

- Feed mechanism (refuse).
- Ash handling system.
- Water treatment.
- Condensate return.
- Pollution control.
- Soot-blowing system.
- Combustion and boiler control system.

SUPPORT REQUIREMENTS

Personnel: 1 man/shift for industrial operation and 2 men/shift for municipal.

Training: Stationary engineer for waste heat boiler and licensed boiler operator for combustion boiler.

Skills Required: Mechanically oriented, pipefitting and electrical.

Inspection: General boiler tubes - refractory and feeding system, air pollution control device and water treatment system, pumps and accessories.

Access: 8-10 ft all around.

Spare Parts: Gauges and general maintenance items.

Permits: As boiler is an accessory to solid waste incineration, all permits necessary for operation of incinerator plus boiler insurance and inspection certificate are required.

OPERATIONAL CONSIDERATIONS

General: A heat recovery boiler should be treated as a supplementary accessory to the solid waste incinerator. This indicates that the disposal rate of solid waste does not depend upon the steam demand. If there is no steam demand, the hot flue from the incinerator bypasses the boiler and is exhausted to atmosphere. It is desirable, however, that in the decision of having a heat recovery boiler with the solid waste incinerator, the demand for steam or hot water should be investigated.

Installation: Depends upon the location of the solid waste incinerator. It is either closely coupled to the incinerator or designed as an incinerator-boiler. For installation as incinerator-boiler, all the considerations of locating a solid waste processing station have to be given.

Maintenance: Routine scheduled boiler maintenance. Half-yearly maintenance is normally required for boiler.

Controls: For waste heat boiler: general boiler operation controls. For incinerator boiler: general boiler controls plus combustion control equipment.

Scheduling: None for boiler itself. It depends upon incineration operation. Such a boiler is an integral part of the incinerator. For incinerator-boiler unit, the storage of solid wastes adequate for continuous operation is desirable.

Downtime: Boiler life (refractory and other accessories) is enhanced with minimum downtime.

Other Factors: As the flue gas originating from the incineration of solid waste contains high concentrations of particulates and acid fumes (from burning of plastics), it is important that scheduled soot-blowing is practiced and the boiler tubes are observed carefully for acid corrosion and fly ash erosions.

SAFETY AND ENVIRONMENTAL CONSIDERATIONS

Installation: Where the incineration project is located.

Fire Hazard: None from the boiler, other than boiler explosion, which seldom occurs.

Explosion: None expected.

Other Safety: Normal automatic controls for boiler operations.

General Environmental: Pollution control equipment dry or wet type is mandatory for the operation.

COST ANALYSIS

Operating Cost

Water Use: Depends upon boiler system design. For 100% condensate return system, the makeup water use is estimated as 3%; for no condensate returning system, 100% makeup water will be required.

Labor: 1-2 man/shift at $20,800/yr including benefits.

Boiler operates normally 24 hr/day but for incinerator-boiler when incineration is stopped. Boiler is down. It keeps normally hot by closing dampers and sometimes by firing with fuel oil or gas.

Maintenance Supplies: 2% of plant facilities investment capital. Maintenance labor = 2% of plant facilities investment.

Life Cycle Cost

Man-hour/ton remains fairly constant for a given size boiler up to 50 tpd capacity. As the input to the boiler is associated with refuse incineration rate, manpower rate is function of incineration load.

Heat recovery boiler is an integral part of the heat recovery incinerator. The capital cost of boiler alone cannot be estimated. The boiler operating cost depends upon the type of boiler and the accessories. For example, a boiler designed with 100% condensate return will have negligible makeup water cost. Otherwise the cost of water use will equal the water equivalent to steam flow rate plus water treatment cost. A waste heat boiler has smaller maintenance and labor cost. Incinerator boilers will require more manpower and maintenance.

Waste heat boiler is part of a heat recovery incinerator system and normally vendors quote boiler cost along with incinerator. Normally an incinerator-boiler system costs $12,000 to $18,000/ton/day capacity of incinerator. The plant facilities investment for 50 tpd incinerator-boiler unit will range from $600,000 to $900,000.

Capital Cost = (plant investment cost + land + organization and startup + interest during contruction + working capital)

Life expectancy of refuse heat recovery boiler = 25 years.

STATE-OF-THE-ART

R&D Needs: Waste heat recovery boiler technology is proven on a variety of plant wastes, which may or may not result in the formation of condensible acids. A low pressure (150 to 300 psig) waste heat boiler utilizing products of combustion of solid waste is subject to acid corrosion of boiler tubes.

Normally, if the gas temperature is higher than 300°F and lower than 800°F, acid corrosion is minimal. However, operating with high exhaust temperatures results in reduced thermal efficiency combustion products from general solid waste will contain a variety of these compounds, and this presents a definite corrosion problem and also possible air pollution concerns. Correction of these problems will impact both the economics and reliability of the waste heat recovery boiler system. R&D in acid corrosion of tubes is needed.

Operating Systems: Very large mass burning incinerators are now equipped with steam generators, examples, Sangus, Chicago, Harrisburg, Nashville, Hamilton, Montreal, Quebec, and many others. Many modular units also are operated at the Nelson Co., Chicago; Casting Engrs, Illinois; Dominion Foods, Illinois; North Little Rock, Arkansas; Masonite Corp, Penn. and many, many others all over the country.

Risks: Use of waste heat recovery boiler itself has little risk. If the incinerator system works, boiler works. Pollution is not related to waste heat boiler but to incinerator.

Other Information: Boilers have good record of operation, and technology is quite developed for highly efficient operation.

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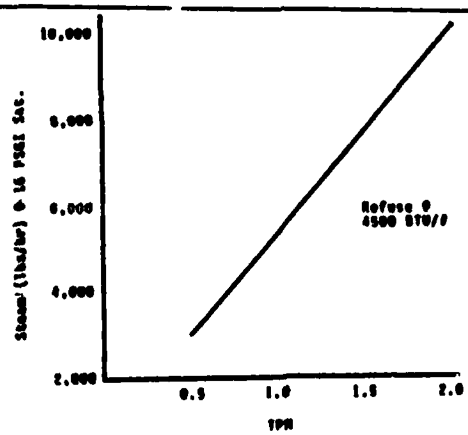


COMPONENT DESCRIPTION

Pyrolysis Chamber

Type
Auger Bed

Physical Characteristics (50 ton/day unit)

A long (110 ft) double-walled cylinder with an inside diameter of about 32 in enclosing a rotating auger attached to a large tubular core. Details of the internals of the auger-reactor are proprietary. The auger is driven by large slow-speed chain drive systems at both ends of the unit.

Principle of Operation

As waste material is slowly augered through the length of the reactor, it is heated by passing hot gases from a furnace between the outer walls of the reactor and through the central core of the auger. The waste is therefore heated by all the surfaces it contacts, as well as mixed and turned by the auger. The gas, oil, and water vapor generated by the reaction are removed for separation through a discharge manifold. The char remaining are transmitted to a conveyor for collection and disposal as waste of solid fuel.

Materials of Construction

Materials of construction are proprietary.

SIZING CRITERIA

For facilities of up to 200 tons/day capacity, the use of multiple 50 tons/day reactors is proposed. Larger facilities would use 200 tons/day reactors.

SUPPORT REQUIREMENTS

No data available

OPERATIONAL CONSIDERATIONS

No data available

SAFETY AND ENVIRONMENTAL CONSIDERATIONS

No data available

COST ANALYSIS

No long-term data are available to make an estimate of design life and life cycle costs.

STATE-OF-THE-ART

Interest in this pyrolysis system has not been sufficient to generate required funds for further development and demonstration. The more rapid development of less technologically complex and innovative methods for the recovery of energy, such as direct combustion, make such further development very doubtful.

History

Development of the auger-type pyrolysis reactor was carried out with private funds in the mid 1970's. Operation of a 50 ton/day facility was demonstrated in 1978 at South Gate, California.

Successes/Failures

The test facilities demonstrated the short-term technical feasibility of the process. Long-term viability and economics have not been demonstrated.

COMBUSTION EQUIPMENT	Pyrolysis	CE-F	P. 1 of 2

COMPONENT DESCRIPTION

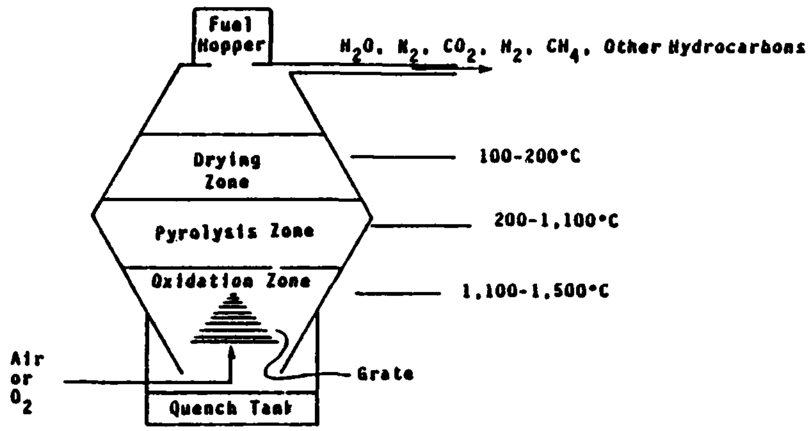
Pyrolysis

Type: Vertical Shaft
Vertical Shaft

Competing Components:
a. Rotary kiln.
b. Dual fluidized bed.
c. Auger

Types Used Commercially: None

Physical Characteristics



Principle of Operation

Waste material is fed in through an airtight seal at the top of the shaft. The material is progressively heated as it works its way down the shaft, first driving off the moisture, then volatilizing the organics, and finally reaching the lower zone where the input of oxygen or air permits combustion to take place.

SIZING CRITERIA

No data available

ACCESSORY COMPONENTS

No data available

SUPPORT REQUIREMENTS

No data available

OPERATIONAL CONSIDERATION

Gas with a sufficient energy content to be considered for external use can only be produced if pure oxygen is used rather than air.

SAFETY AND ENVIRONMENTAL CONSIDERATIONS

No data available

COST ANALYSIS

Pyrolysis is a capital and technology intensive process. Its feasibility in small-to-medium scale energy recovery operations is doubtful at its present state of development.

STATE-OF-THE-ART

No facilities for waste to energy conversion, other than proof-of-concept, pilot plants, and research and development work have been constructed and operated successfully. The economics of the system, and competition from other, less complex systems places further development in doubt: Davey Powergas Systems, Union Carbide.

Gasification systems of this type can trace their development back to the technology developed 80 to 100 years ago for production of gas from coal and wood. PUROX (Union Carbide) has been under development for several years, with a redesigned and upgraded facility now in the final design phase.

COMBUSTION EQUIPMENT	Pyrolysis	CE-G	P. 1 of 2

COMPONENT DESCRIPTION

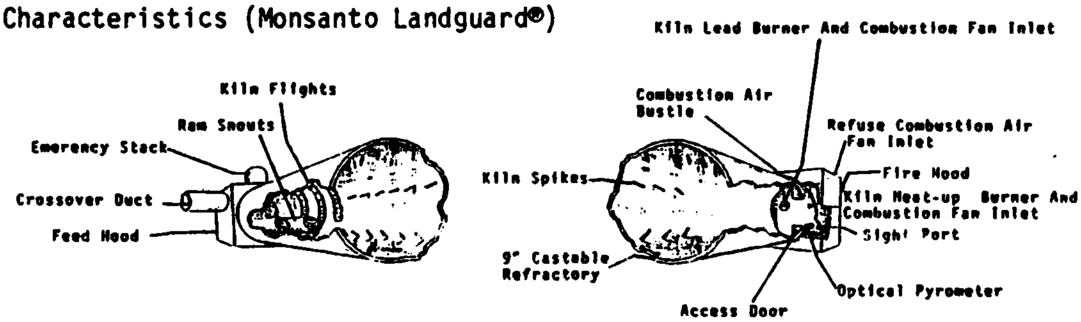
Pyrolysis Chamber

Type
Rotary Kiln

Competing Components:
a. Vertical shaft.
b. Auger.
c. Dual fluidized bed.

Types Used Commercially: None

Physical Characteristics (Monsanto Landguard®)



General Description

The kiln shown is 19 ft in diameter, 100 ft long , and rotates at 2 revolutions per minute. The refractory lining keeps the heat of the reaction within the kiln and prevents erosion of the kiln shell. Additional heating requirements are provided by fuel oil burners in the lower end of the shaft.

Principle of Operation

Waste is fed into the inclined rotating kiln through ram feeders. The kiln flights and spikes churn the waste as it passes down the kiln, being partially combusted as it moves from the inlet end to the burners. The pyrolysis gas is removed at the upper end and is combusted in later processes.

Materials of Construction

Refractory Lining: Various castable refractory materials were used with limited success while operating as a pyrolysis unit.

OPERATIONAL CONSIDERATIONS

Numerous operational deficiencies were encountered with the rotary kiln pyrolysis reactor as originally designed. Resolutions of those problems involved conversion of the kiln from a pyrolysis reactor to starved-air incinerator.

COST ANALYSIS

No long-term data are available to make an estimate of design life or life cycle costs.

STATE-OF-THE-ART

Due to the development of competing energy technologies, and the demonstrated difficulty in proving the economic and technological viability of pyrolysis of wastes, continued interest is very limited.

History: Development began with a small scale (0.3 to 0.6 ton/day) prototype in 1968 and a 35 ton/day prototype in 1969. Further development of another 35 ton/day facility in 1974 led to the design of a 1,000 ton/day facility later that same year.

Successes/Failures: The 1,000 ton/day facility did not operate as originally designed. After multiple efforts to modify and retrofit to improve performance, the use of pyrolysis was abandoned in favor of starved-air incineration.

Key Problems: Failure of the refractory lining; lack of sufficient control of input material; insufficient temperature control leading to slagging or incomplete reactions.

COMBUSTION EQUIPMENT	Fluidized Bed	CE-H	P. 1 of 5

COMPONENT DESCRIPTION

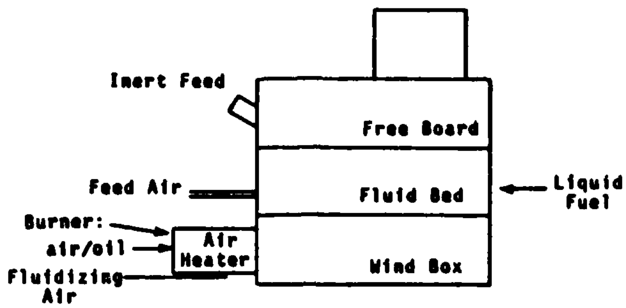
Fluidized Bed Combustor (AFBC) — Type: Atmospheric

Types Available - Competing Components
  a. Solid burning (atmospheric)
  b. Solid burning (pressurized)

Types Used Commercially
None

Physical Characteristics

FBC



General Description

Fluidized bed combustor consists of a lower section called windbox for distributing fluidizing air, a midsection containing inert solid particles of high fusion temperature where feed is inserted and reaction occurs, and the upper section called freeboard where combustion products pass out of the bed. The ancillary equipment includes storage and retrieval bin for pulverized solid waste, the feed mechanism, the fluidizing blower, the cyclone, the ash removal system and waste boiler and accessories.

Principle of Operation

The fluid bed is a dense uniform suspension of inert solids maintained in a turbulent motion by an upward moving airstream. The turbulent mixture of air and solids behaves as if it were a fluid and possesses characteristics of a boiling liquid. The temperature of the inert bed is raised to the ignition temperature of the material. The waste material is added to the bed and the optimum contact between inert solids and refuse occurs by the large surface area of the inert solids causing rapid heat transfer and subsequent combustion.

Materials of Construction

1. Low carbon hot-rolled steel casing ASTM-36 or equivalent.
2. Refractory insulating firebricks and L. I. firebrick facing or castables.

Advantages Over Other Types

High heat reservoir (16,000 Btu/ft^3 at 1,400°F), extremely high combustion efficiency (90%), low excess air, reduced size for flue gas handling and cleaning equipment, negligible unburned hydrocarbons negligible NO_x, and low operating temperature. Such units have high volumetric heat generation rates leading to compact combustor size and lower unit capital costs. The combustor is flexible to accept solid, liquid, gas, slurry, and sludge feed without affecting operation.

SIZING CRITERIA

- Waste flow rate.
- Volumetric heat generation rate - (100,000-200,000 Btu/hr-ft^3).
- Percent combustion efficiency (80-90%).
- Percent heat exchange efficiency (50-80%).

Steam Production = 3.22 lb/lb of refuse at 4,500 Btu/lb.

ACCESSORY COMPONENTS

- Screw or Ram feeder.
- Fluidizing blower.
- Auxiliary fuel oil or gas burner for high moisture feed (sludge type).
- Ash removal system (quench tank, etc.).
- Venturi scrubber or cyclone.
- Front-end loader.
- Dump trucks.

SUPPORT REQUIREMENTS

Personnel: 10 tpd = 1 man-hr/ton, 40 tpd = 0.25 man-hr/ton.

Training: Trainee - 1 mo, Apprentice - 3 mo.

Skills Required: Stationary engineer, electrical and pipe fitting and mechanics.

Inspections: Emissions, health and safety - semi-annual.

Access: 15 ft on all sides for front-end load and dump truck.

Spare Parts: All major components related to feed prepartion, drives, and conveyors.

Permits: Environmental impact, emissions, noise, zoning, and building.

OPERATIONAL CONSIDERATIONS

General: If the function of the AFBC is to dispose of solid waste, the unit can be operated to meet the solid waste disposal rate need. However, if the AFBC is to generate steam or electricity, the waste disposal rate has to be maximized to meet steam or electricity commitment.

Installation: Close to energy use if waste energy is being utilized, otherwise close to solid waste generation source.

Maintenance: Inert bed level has to be maintained and monitored. The air flow rate through the perforated bed plate needs to be watched and regular ash dumping should be scheduled.

Controls: Semi-automated with manual override.

Scheduling: Prepared refuse storage 2 days capacity to smooth out operation.

Downtime: Minimum short-term downtime.

SAFETY AND ENVIRONMENTAL CONSIDERATIONS

General: Plant site access to refuse trucks, fire and ambulance.

Locations: Outlying part of the Navy base, away from congested personnel housing.

Fir Hazard: None from AFBC proper. However fire hazard exists in indoor refuse receiving, processing, and storage. Processing plant building should be provided with sprinkler system, fire hydrant, and smoke alarm system.

Explosion: None.

Other Safety: Auxiliary fuel lines (liquid and gaseous) provided with automatic shutoff valves.

General Environmental: General appearance and aesthetics acceptable to visitors. Maloderous situation can be avoided by using deodorizers and by providing for waste receipt to match processing load.

COST ANALYSIS

Life Cycle Analysis:

STATE-OF-THE-ART

R&D Needs:
- Means to prevent plugging of air distribution board.
- Ash removal without losing inert bed material.
- Slagging problem.
- Uniform distribution of fluidizing air.

Operating System: None. Experimental unit operated at Combustion Power Company, Inc., Menlo Park.

Manufacturer: ERCO, Combustion Power, Johnston, York-Shipley, Fluidyne.

Risks: The disposal of solid waste in fluidized bed combustor has not been developed to commercial status.

Other Information: Fluidized bed combustor has wide applications. Federal (DOE) funding is forthcoming to Combustion Power and Argonne National Lab to conduct demonstration of AFBC for solid waste disposal process.

History: The solution to the need for multi-fuel burners capable of achieving high efficiency in combustion is found in the technology of fluidized bed combustion. This combustor is capable of burning all kinds of fuels either individually or simultaneously. It does so with improved efficiency and emission performance that can meet EPA standards.

Failures: Most failure occurs when glass contents of the solid wastes melt and plug the holes of the air distribution plate. Slagging is another problem.

Key Problems:

- Plugging of air distribution plates.
- Excessive slagging that causes clinker to form.
- Refractory wear.
- High inert material loss.
- Nonuniform fluidizing air distribution.

Comments: Additional Data

The future of solid waste disposal thrugh AFBC is uncertain. ERCO, Combustion Power, Johnston, and many other companies have invested large sums of money but have not been successful. The key problem is slagging, melting of glass and nonmetals, and critical fluidizing parameters that are difficult to attain with solid waste as feed.

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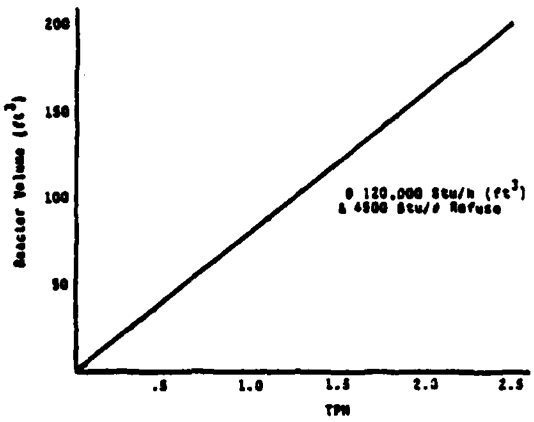
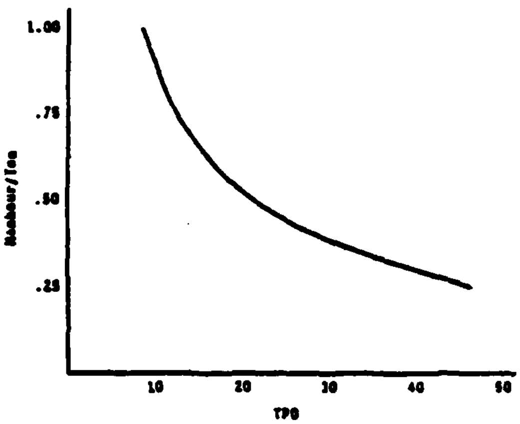
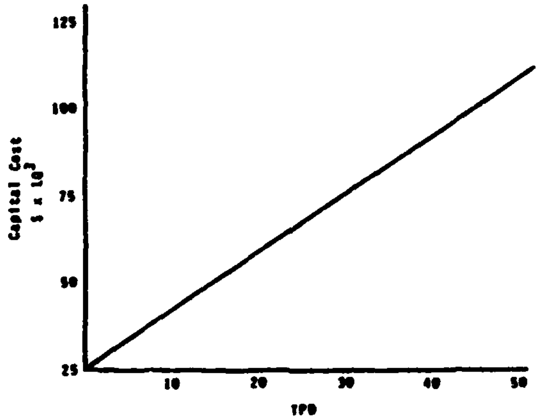
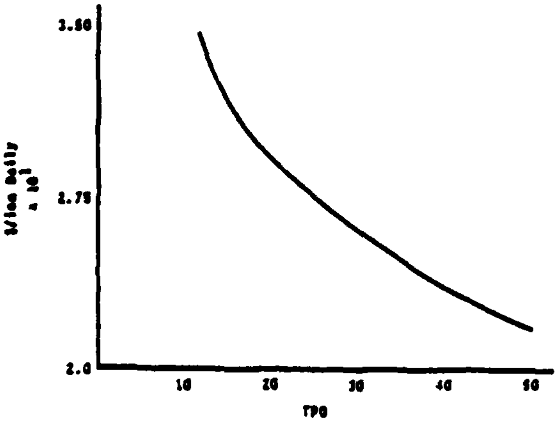
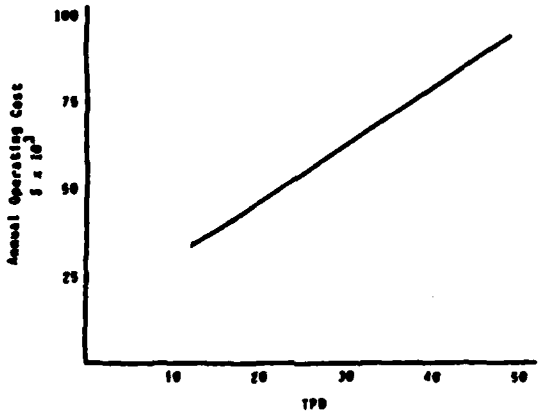
COMBUSTION EQUIPMENT	Fluidized Bed	CE-H	P. 5 of 5











COMBUSTION EQUIPMENT	Pyrolysis	CE-I	P. 1 of 2

COMPONENT DESCRIPTION

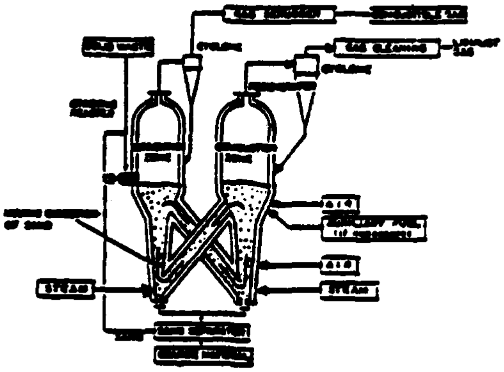
Component
Pyrolysis Chamber

Type
Dual Fluidized Bed

Competing Components:
a. Vertical shaft.
b. Auger.
c. Rotary kiln

Types Used Commercially: None

Physical Characteristics



General Description

Two vertical shafts connected so as to allow the movement of the contained materials from the top of each reactor to the bottom of the other. Force for the fluidization of the sand/refuse mixture is provided by the injection of steam at the bottom of each reactor.

Principle of Operation

By dividing the pyrolysis unit into two chambers, the heating requirements of the pyrolysis reactions can be met without contaminating the pyrolysis gas with carbon dioxide from the combustion process or nitrogen from the intake air. In one chamber, sand or other carrier is heated by the combustion of refuse with air and the injection of steam. The hot sand is then transported to the other reactor, where pyrolysis of refuse takes place in the absence of air.

Advantages Over Other Types

Use of the solid waste to provide most of the energy required by the process without contaminating the product gas with combustion products.

STATE-OF-THE-ART

The use of dual fluidized beds represents one of the few pyrolysis technologies still under active development. Results from the facility presently in construction should be analyzed before further development is considered.

History:

Development of the system shown has occurred in Japan. After small-scale tests in 1972-1974, a 40 ton/day demonstration plant was constructed. The first commercial plant is under construction near Tokyo, with a capacity of 450 ton/day.

Success:

No data on the performance of the full-scale facility are available. The demonstration plant has been used to test the disposal of municipal refuse, pulp and paper sludge, and plastic waste.

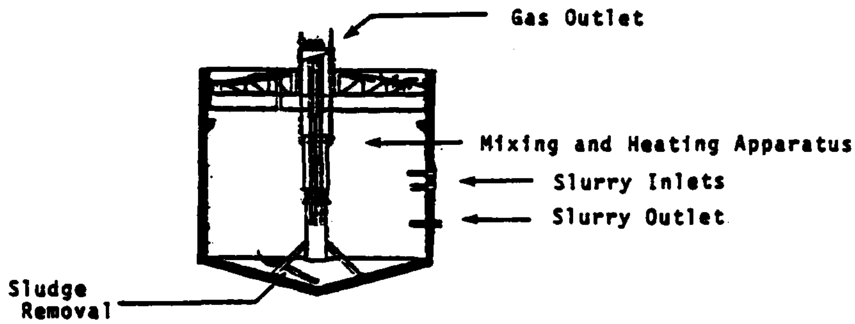
COMBUSTIION EQUIPMENT	Anaerobic Digestion	CE-J	P. 1 of 2

COMPONENT DESCRIPTION

Digestion Tank

Type
All

Physical Characteristics



General Description

Sidewalls and bottom are commonly field-constructed of reinforced concrete. Top is either a floating or fixed steel cover with entryways (for maintenance) and the mixing and gas draw-off systems.

Principle of Operation

Waste enters the digester in a slurry (approximately 12% solids) and is retained in the digester for a residence time of 5-15 days. Heat is provided by recirculating heated slurry or by heating coils. Gas from the decomposition of the wastes is drawn off the top of the tank, while waste slurry is drawn off from the bottom or center. Mixing can either be mechanical or by recirculation of the product gas.

Materials of Construction

Larger systems are primarily reinforced concrete with smaller tanks constituted of mild steel with a corrosion protection coating.

SIZING CRITERIA

The digester is sized to provide the required retention time at the specified slurry solids concentration. Solids concentration is limited by the inability to pump or to provide mixing and heat transfer in thick slurries. Typical conditions would require 250-300 cu ft of digester per input ton of slurry solids.

SUPPORT REQUIREMENTS

Personnel: System could be automated to provide unattended operation overnight, but daily feeding and performance check is required.

Skills Required: Laboratory analysis of wastewaters and sludges, mechanical repair.

OPERATIONAL CONSIDERATIONS

Digesters are sensitive to the skill of the operator. The rapid determination of the causes of digester upsets, and the ability to eliminate them, are essential to providing a working system.

SAFETY AND ENVIRONMENTAL CONSIDERATIONS

General: Effluent sludges, especially from high temperature systems, are relatively pathogen-free and can be disposed of in sanitary landfills.

Explosion: Improper operation can result in an unsafe build-up of gas pressure within the system, or an accumulation of methane gas in buildings.

COST ANALYSIS

Estimated cost of the digester in a 20-ton/day system is $100,000 to $200,000.

STATE-OF-THE-ART

R&D Needs: Digester design is relatively well developed. Problem areas are in pumping, heating, and disposal of the slurry for solid waste digestion.

Operating Systems: Many systems are operating at sewage treatment facilities. A solid waste digester is being operated by Waste Management, Inc. at Pompano Beach, Florida.

Manufacturers: Envirotech, Ralph B. Carter, Rex-Chainbelt, and many others.

Risks: A long-term track record of operation using a solid waste feed has not yet been established.

History: Anaerobic digesters have been used for decades at sewage treatment facilities. Their use for large-scale waste conversion to energy has been researched at least since the 1960's. Based on the bench and pilot-scale studies carried out primarily at academic institutions, Waste Management, Inc. has constructed a 100 ton/day facility for testing and evaluation.

Failures: System failures due to improper operation, non-biodegradable feed material, and mechanical breakdown were common in the R/D work.

Key Problems: Feed material is an abrasive fluid with extremely poor pumping characteristics. Systems which are designed to function well under one set of operating conditions can easily fail if these conditions are altered.

COMPONENT DESCRIPTION

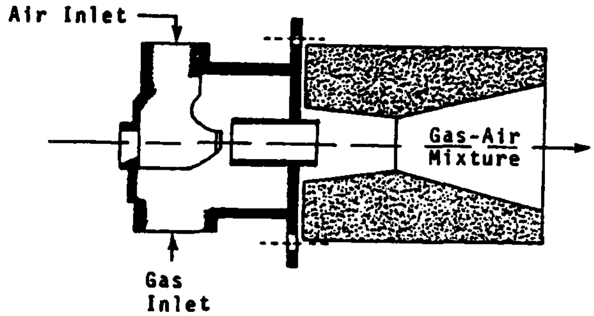
Gas Burner

Type
Fuel gas produced from gasified refuse

Types Available
a. Pipeline - quality gas burner
b. Low Btu gas burner (LBG)
c. Medium Btu gas burner (MBG)

Types Used Commercially
a, b

Physical Characteristics



General Description

Industrial gas burners may be classified as premixing, nozzle mixing and long-flame burners, according to the position and manner in which the gas and primary combustion air are brought together. Gas burners are either of atmospheric or high-pressure type. "Closed" type burners usually supply all of the air for combustion through the burner, whereas the "open" type may induce air flow into the combustion space through the opening around the burner. Many burners are equipped as either an open or a closed burner. An industrial burner normally is fitted with a burner tile (refractory block) with a conical or cylindrical hole (flame tunnel) through its center. The tile serves to maintain ignition and to reduce flash-back and blow-off. Some LBG burners are equipped with a pilot flame.

Principle of Operation

The functions of a burner, are to deliver fuel and air to the combustion space, to turbulently mix the fuel and air, and to provide for continuous ignition of the fuel-air mixture. Some of the important factors to be considered in gas burner operation are fuel/air mixture, flue gas volume, flame temperature, flame shape, stability, turndown ratio and ignitability. The ultimate objective of every gas burner is to transform the thermal energy of the gas into useful heat which is absorbed by the object being heated.

Refuse-derived fuel gas may be of Low Btu Gas (LBG) (as from Torrax Process), or Medium Btu Gas (MBG) (as from Purox Process). LBG contains 1/7 to 1/6 of the energy on a volumetric basis that of a pipeline quality gas. The stoichiometric air/fuel mixture, which establishes the burner size and other requirements, increases only by 30 to 40% and the flue-gas volume is only 19 to 21% more for LBG than natural gas. For MBG, the combustion-air requirements are only about 5% greater than those for pipeline quality gas. The amount of flue-gas produced by the combustion of MBG is about the same as it is for pipeline quality gas.

In Scroll-type burners, the LBG is introduced through a large Scroll to inject the gas stream into the combustion zone into annulus between two zones of combustion air. By introducing the LBG between two counter-rotating air streams, the burner promotes rapid mixing of the gas and air. The result is the successful combustion of a variety of low pressure LBG within existing boilers, new cold furnaces, high heat release boilers or other process furnaces. Heat release rate per unit volume of LBG is quite different from natural gas so the burner for LBG is to be designed for ignition stability and load range factor.

Materials of Construction

1. Scroll: Stainless steel (18-8).
2. Burner-Throat: High alumina refractory.

Advantages Over Other Types

- Scroll-type burner allows large volume of LBG with a very low pressure drop, and eliminates the need for gas boosters or gas compressors.
- Such burners can accept supplementary fuel oil or natural gas in any quantity up to and including full burner capacity.
- Such burners can accept LBG of varying heating value and maintain flame stability.
- The large openings in the gas Scroll allow passage of tar particulates that are usually found in LBG streams.

SIZING CRITERIA

To arrive at a burner size, the following information is needed:

- Chemical composition of the gas (proximate and ultimate analysis).
- Heating value.
- Temperature.
- Volume Rate.
- Tar and particulate concentration, if any.
- Gas pressure.
- Required volumetric heat release rate.
- Single fuel or dual fuel; if dual fuel, what is the alternate or supplementary fuel.

Size

- 10×10^6 Btu/hr or larger. (See graph on Page 4.)

ACCESSORY - COMPONENTS

- Gas regulator.
- Pilots.
- Purge interlock.
- Flame detector (UV or IR).
- Automatic shut-off valve of fuel on failure of air supply.
- Closed-position switch for burner shut-off valves.
- Shut-off of fuel in the event of low fuel pressure and excessive fuel-gas pressure.

SUPPORT REQUIREMENTS

Personnel: (Operating): None. Burners are an integral part of a combustor. Burning of a gaseous fuel is maintained automatically by the burner control device. Safety equipment and accessories protect the combustor and the installation from fire hazard.

Maintenance Personnel: Burners using closed-coupled gasifier producing low or medium Btu gas are subjected to dirt, tar, and other fouling elements and need routine and constant maintenance. Manufacturer's guidelines for maintenance in cleaning, adjustment, and replacement of worn out parts is normally followed.

Skills Required: Mechanical aptitude, electrical wiring, and other piping work.

Inspections: Occasional or monthly flue gas analysis by Orsat or other instrument to estimate the combustion efficiency (% CO in flue gas).

Access:

- Frontal room adequate to remove the burner gun barrel.
- Adequate room for workers to rebuild or to replace the refractory burner block.
- Access for overhead crane or jury-rigging to hold and hang the burner assembly.

Spare Parts: As advised by the burner manufacturer. Burner accessories like fuel gas regulator and flame detector, etc., should be stocked.

Permits: Nothing separate but Factory Mutual or equivalent agency's approval will be required to obtain the necessary insurance coverage.

OPERATIONAL CONSIDERATIONS

General: LBG cannot be transported to long distance point, so the gasifier should be in close proximity to the burner. The burner should be piped for burning at least one additional fuel type (gas or oil). In case of gasifier breakdown, the burner could be switched to the alternate fuel to maintain the thermal input to the combustor or boiler.

Installation: A closed-coupled gasifier enables the burner and the combustor to reap the benefit of the sensible heat recovery from the gas. A heated gas/air mixture produces higher flame temperature, increases flame stability, decreases flame blowout, and increases overall thermal and combustion efficiencies.

Controls: Gas/air flow ratios, flame stability and flame failure.

Downtime: Scheduled maintenance will minimize downtimes.

SAFETY AND ENVIRONMENTAL CONSIDERATIONS

General: For a burner properly designed to burn a specific refuse-derived fuel gas would normally be able to achieve complete combustion of the fuel. Natural gas burning generates considerable NO_x. Therefore the burning of LBG is expected to produce some NO_x. Some of the prevailing steps such as staged combustion, reduced air and other devices may be required to reduce NO_x emission (depending upon the existing local, state, and federal regulations for the specific process).

Fire Hazard: Burner safety controls should be kept in excellent working condition. Normal fire safety steps of water house, sprinkler system, etc., are recommended.

Explosion: Pipeline carrying LBG should be designed and built to prevent gas leakage and consequent explosion.

Other Safety: Safety shut-off valves in fuel line, for low and high fuel pressure, for fan failure and flame blowout.

COST ANALYSIS

A gas burner is merely an accessory to a combustor or a boiler. The maintenance cost and capital involve replacement of parts only and is very nominal in reference to the overall maintenance and life cycle costs for a waste-to-energy recovery system. (See graph on Page 4.)

Capital Cost (per quotation - COEN burner)

Note: Burner safeguard, combustion control, fan and accessories cost 80% of the burner assembly cost and the equipment is same for all size burners. So there is very little cost change for a burner with size.

STATE-OF-THE-ART

R&D Needs:

- LBG generally has high concentrations of particulate matter. Hot gas clean-up system should be developed if the sensible heat of the gas is to be recovered.
- LBG contains high moisture and tar. For a gas system where the gas has to be transported to a short distance (i.e., the system that is not closed-complete with a boiler/combustor), the gas should be scrubbed to take out particulate matter, tar, and moisture. A R&D program involving such gas cleaning system is essential.
- Appropriate NO_x emission control device should be developed.

Operating Systems: Refuse-derived LBG or MBG systems are not operating in the United States at this time. The Torrax Process has been installed in several locations in Europe and they are operating with limited success. The Purox System has been demonstrated by the production of MBG in the private sector. Enterprise and Pan-American Systems have the potential to produce LBG/MBG.

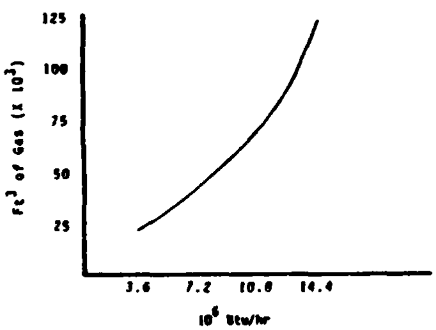
Manufacturers:

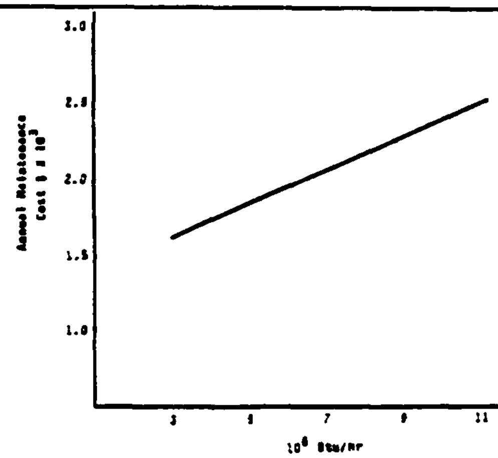
- COEN Co., Burlingame, California.
- North American Burner - Cleveland, Ohio.
- Eclipse Fuel Eng. - Rockford, Illinois.
- Maxon Burner Co. - Muncie, Indiana.
- Other boiler manufacturers.

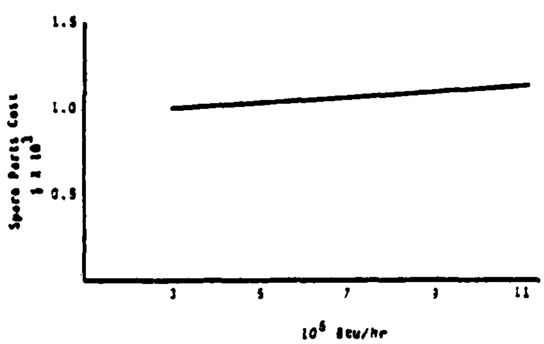
Risks: Coal-derived LBG and MBG have been successfully test-fired. Burner manufacturers have LBG burners in catalogues. The technology has been developed and demonstrated, and is now commercially available.

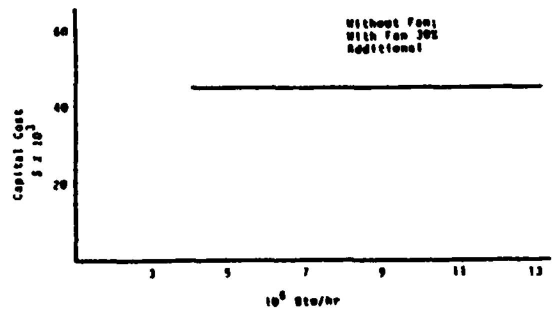
REFERENCES

1. North American Combustion Handbook, published by North American Manufacturing Co.
2. Combustion - A reference book on theory and practice published by AGA.
3. Steam - published by Babcock & Wilcox.
4. Fuels & Combustion - authored by Smith & Stinson, McGraw-Hill.
5. COEN Company's catalog.









COMPONENT DESCRIPTION

Oil Burner

Type
Light Oil

Types Available
a. Air atomized
b. Steam atomized
c. Mechanically atomized

Types Used Commercially
a, b, c

Physical Characteristics

General Description

A burner is a device for feeding fuel and air to the boiler such that combustion can be maintained. The burner is designed to give the proper mixing between oil and air to sustain combustion over whatever the burner's operating range may be.

Principle of Operation

First the oil must be atomized or converted to a fog. The oil is atomized by blowing through a nozzle with dry steam or air or pressure or mechanical device. The air and oil can be mixed with the oil and flame in one step or through several stages by use of multi-register burners or overfire air ports.

Materials of Construction

Normal tool steel can be used. If the oil is mixed with abrasive solids, the nozzle will require modification. Special tungsten-carbide inserts have been used. Ceramic inserts are also in the developmental stage.

Advantages Over Other Types

Steam-atomized burners have a wider operating range but have steam losses. Mechanically-atomized burners require less energy but may require more maintenance. Some smaller units may also use air atomization. When the oil contains solid particles, air or steam atomization is preferred over mechanical.

SIZING CRITERIA

The size depends on the size of the boiler and turndown required. Firetube units tend to have one burner only. Larger watertube units may be multiburner.

ACCESSORY COMPONENTS

- Fuel pumps.
- Forced draft fans.
- Burner and combustion controls.

SUPPORT REQUIREMENTS

Personnel: Boiler operator

Training: Boiler operator

Skills Required: Boiler operation

Inspections: Boiler certification

Access: Burner assembly can be pulled out

Spare Parts: Guns and nozzle

Permits: Air pollution control district

OPERATIONAL CONSIDERATIONS

General: Most problems involve nozzle deterioration so oil should pass through a strainer.

Installation: The burner sizes (firing rate and physical dimension) vary dependent on boiler size, and shape.

Maintenance: Nozzle and fuel pumps give most problems.

Controls: Air, fuel feeds are controlled to give required steam or hot water.

Scheduling: Can be changed while boiler is still hot.

Downtime: Very small.

Other Factors: Guns are usually retracted when not in use.

SAFETY AND ENVIRONMENTAL CONSIDERATIONS

General: Major safety control device is flame detector.

Fire Hazard: Leaks in fuel lines could start fires as well as cause loss of oil pressure.

Explosion: If flame goes out, explosion could result if fuel flow is not stopped.

Other Safety: Also bad combustion can produce CO which is toxic and an explosion hazard.

General Environment: Burning conditions influence NOx, CO, hydrocarbon and particulate emissions.

COMBUSTION EQUIPMENT	Liquid Fuel	CE-L	P. 3 of 3

COST ANALYSIS

$8,200 for 10x10[6] BTU/hr unit - includes pump, controls, fan - equipment cost only.
$33,000 for 75 x 10[6] BTU/hr unit - includes pump and controls - equipment cost only.

Cost Are Manufacturer's Estimates

STATE-OF-THE-ART

R&D Needs: Low No_x burners and burners for oil -- solid slurries.

Operating System: Better combustion controls to increase efficiency.

Manufacturers:

- CEA.
- Combustion.
- COEN.
- Forney.
- North American Manufacturing.
- Peabody.
- Ray.
- Zink.
- Zurn.
- Others.

Risks: Low NO_x burners may cause flame impingement and flame instability.

Other Information: Low excess air burners are also a promising area.

History: Oil burners have been around for many years. Waste fuels have also been burned for long periods. The problems have arisen when the oil was dirty and gave burner plugging problems. Also, if waste oil characteristics are much different than that of the light oil, only small amounts of waste oil are usually used.

Comments: Additional Data

The burners described are typical light oil burners. If the waste oil is different than light oil, there could be problems with flame stability. Also if solid waste is mixed with the oil, the nozzle must be checked for erosion. Changes in the flame shape could indicate nozzle erosion. Also the waste fuel must be free of dirt to prevent plugging of nozzle.

REFERENCES

1. Field, E. M., "Oil Burners," 1977, Audel & Company, Indianapolis, Indiana.
2. "Steam" by Babcock & Wilcox.

COMBUSTION EQUIPMENT	Liquid Fuel	CE-M	P. 1 of 3

COMPONENT DESCRIPTIOIN

Oil Burner

Type
Heavy Oil

Types Available
a. Air atomized
b. Steam atomized
c. Mechanically atomized

Types Used Commercially
a, b, c

Physical Characteristics

General Description

A burner is a device for feeding fuel and air to the boiler such that combustion can be maintained. The burner is designed to give the proper mixing between oil and air to sustain combustion over the burner's operating range.

Principle of Operation

First the oil must be atomized or converted to a fog. The oil is atomized by blowing through a nozzle with dry steam or air pressure or mechanical device. The air and oil can be mixed with the oil and flame in one step or through several stages by use of multi-register burners or overfire air ports.

Materials of Construction

Normal tool steel can be used. If the oil contains abrasive solids, the nozzle will require modification. Special tungsten-carbide inserts have been used. Ceramic inserts are also in the developmental stage.

Advantages Over Other Types

Steam-atomized burners have a wider operating range but have steam losses. Mechanically-atomized burners require less energy but may require more maintenance. Some smaller units may also use air atomization. When the oil contains solid particles, air or steam atomization is preferred over mechanical.

SIZING CRITERIA

The size depends on the size of the boiler and turndown required. Firetube units tend to have one burner only. Larger watertube units may be multiburner.

COMBUSTION EQUIPMENT	Liquid Fuel	CE-M	P. 2 of 3

ACCESSORY COMPONENTS

- Fuel pumps.
- Forced draft fans.
- Burner and combustion controls.

SUPPORT REQUIREMENTS

Personnel: Boiler operator

Training: Boiler operator

Skills Required: Boiler operation

Inspections: Boiler certification

Access: Burner assembly can be pulled out

Spare Parts: Guns and nozzle

Permits: Air pollution control for entire boiler system.

OPERATIONAL CONSIDERATIONS

General: Most problems involve nozzle deterioration so oil should be strained.

Installation: The burner sizes vary dependent on boiler shape.

Maintenance: Nozzle and fuel pumps give most problems.

Controls: Air, fuel feeds are controlled.

Scheduling: Can be changed while boiler is still hot.

Downtime: Very small.

Other Factors: Guns are usually retracted when not in use.

SAFETY AND ENVIRONMENTAL CONSIDERATIONS

General: Major safety control device is flame detector.

Fire Hazard: Leaks in fuel lines could start fires as well as cause loss of oil pressure.

Explosion: If flame goes out, explosion could result if fuel flow is not stopped.

Other Safety: Also bad combustion can produce CO which is explosion hazard.

General Environmental: Burning conditions influence NOx, CO, hydrocarbon and particulate emissions.

COST ANALYSIS

$13,000 for 10 x 10^6 BTU/hr unit - includes pump, controls, fan -- equipment cost only.
$33,000 for 75 x 10^6 BTU/hr unit - includes pump and controls - equipment cost only.

STATE-OF-THE-ART

R&D Needs: Low NO_x burners and burners for oil - solid slurries.

Operating Systems: Better combustion controls to increase efficiency.

Manufacturers:

- CEA.
- COEN.
- Forney.
- North American Manufacturing.
- Peabody.
- Ray.
- Zink.
- Zurn.
- Others.

Risks: Low NO_x burners may cause flame impingement and flame instability.

Other Information: Low NO_x burners are also a promising area.

History: When one installation tried to mix waste with heavy oil, their steam-atomized burners led to incomplete combustion and burner fouling. They solved the problem by switching to low excess air.

Successes: Parallel flow burners. The new burners used natural gas as the atomizing medium. They also only fire 4 out of 6 burners on the waste fuel. (See January 1981 issue of "Power," McGraw-Hill.)

Comments: Additional Data

The burners described are typical heavy oil burners. If the waste oil burned is different than heavy oil, there could be problems with flame stability. Also if solid waste is mixed with the oil, the nozzle must be checked for erosion. Changes in the flame shape could indicate nozzle erosion. Also the waste fuel must be free of dirt to prevent plugging of nozzle.

REFERENCES

1. Field, E.M., "Oil Burners," 1977, Audel & Company, Indianapolis, Indiana.
2. "Steam" by Badcock & Wilcox.

COMBUSTION EQUIPMENT	Liquid Fuels	CE-N	P. 1 of 4

COMPONENT DESCRIPTION

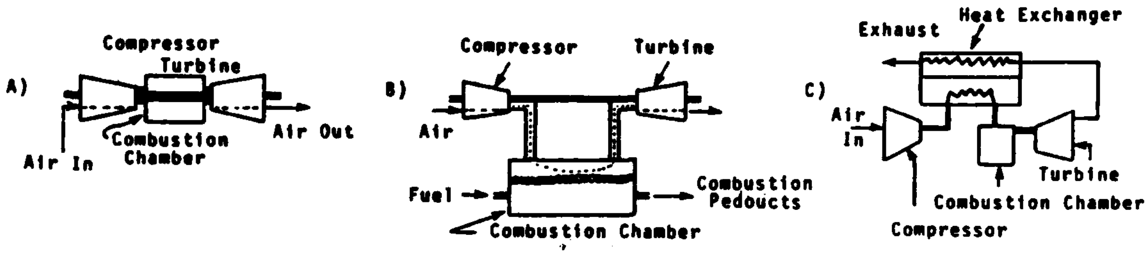
Gas Turbines

Type
Continuous Combustion

Types Available: a. Direct fired
b. Indirect fired
c. Regenerated

Types Used Commercially
a, b, c

Physical Characteristics



General Description

Gas turbines are continuous combustion engines consisting of an axial or radial compressor, combustion system, high pressure (compressor drive) turbine and a low pressure (power) turbine. The regenerated turbines also have a heat exchanger.

Principal of Operation

Air (or exhaust gas) is compressed, heated, and expanded. The expansion produces the power required by the compressor as well as a net power output. The power output is dependent on the mass flow rate, the inlet temperature, and the pressure ratio.

Materials of Construction

- Compressor: high strength alloys.
- Combustor: corrosion and high temperature resistant alloys.
- Turbine: alloys displaying 9000 creep, fatique corrosion and erosion resistance.

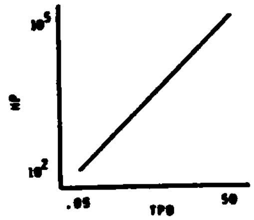
Advantages Over Other Types

Instrumented for remote operation, quick and easy installation, high horsepower to size ratio, short start-up time, relatively vibration-free.

SIZING CRITERIA

Load: Kilowatts or horsepower = 100 - 100,000 hp design operation.
Fuel Consumption: Specific fuel consumption, tons per day.

Size of Turbine



Based Upon Specific Fuel Consumption Of 0.36 LB/HP-HR

ACCESSORY COMPONENTS

- Fuels treatment.
- Storage tanks.
- Cogenerator (heat recovery)
- Water cleaning/injection for pollution/NOx control.

SUPPORT REQUIREMENTS

Personnel: Systems automated can be unattended (statutory requirements).

Training: Minimal for operation, extensive for maintenance.

Skills Required: Maintenance personnel/mechanic.

Inspections: Regular inspections required, depends on duty.

Access: Minimum needed for maintenance removal.

Spare Parts: Spares and maintenance/support available from manufacturers.

Permits: Must meet EPA emissions criteria.

OPERATIONAL CONSIDERATIONS

General: Waste usage increases with demand.

Installation: Fuel and electrical hookup.

Maintenance: Cleaning, borescope inspection.

Controls: Mostly automated.

Scheduling: 24 hour operation possible.

Downtime: Startups hardest on engine. Maintenance down time frequent, and often lengthy.

SAFETY AND ENVIRONMENTAL CONSIDERATIONS

General: Noise control, covered air intakes.

Fire Hazard: Exhaust temperatures range from 850° - 1100°F.

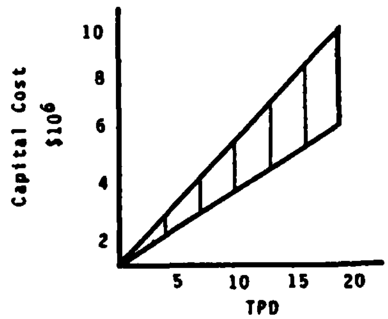
Explosion: Possibility if startups fail. Mc le plugging can cause irregular flame pattern.

Other Safety: Over-speed shutdown, vibration shutdown, lubrication monitor/shutdown.

General Env.: Emissions must be monitored, can be adjusted, depending on fuels.

COMBUSTION EQUIPMENT	Liquid Fuels	CE-N	P. 3 of 4

COST ANALYSIS



Based Upon $50-70/kw

Maintenance Costs: $7.50/kw-year.

Supplemental fuel to burn 10 tons/day = $20k.

STATE-OF-THE-ART

R&D Needs: Combustor design to handle variety of fuels.

Operating Systems: Electric generation, propulsion, pipeline pumping.

Manufacturers: Major engine manufacturers.

Risks: N/A.

Other Information: Can burn most types of liquid fuel with some treatment.

Cost of Equipment: Data unavailable.

History: Developed during World War II, the turbines have undergone significant development. Currently, they are used as reliable airplane engines, in marine propulsion, pipeline and electric generation.

Successes: Coast Guard successfully burned a .5 percent mixture of spent lube oil in 1973. Manufacturers okayed this mixture. Many engines have been burning Bunker C which can be as dirty.

Failures: Exhaust temperatures are high if cogenerators are not used, without such a significant loss in efficiency occurs. No data is available to suggest that waste oil has been unsuccessfully burned.

Key Problems: Turbines work at high internal temperatures. The temperatures multiply corrosion problems. Cooling of higher temperature models. Ability to handle wide variety of fuels. Each major increase in firing temperatures requires major component improvement.

Comments: If the gas turbine is on site, it can be adapted to burn waste-derived oil or spent motor oils in low mixtures. Higher mixtures could be used if the waste oils are cleaned. The cost of supplemental fuel is the main consideration. Unless the turbine is going to be used all the time, it is not viable to burn waste oil in them.

REFERENCES

1. "Internal Combustion Engines," Edward F. Obert, Harper & Row, 1973.
2. "Sawyer's Gas Turbine Engineering Handbook," 1976. Vol. I, II, III.
3. Melior, A. M., Leonard, P.A., Henderson, R. E., "Turbopropulsion Combustion Research Needs," ASME paper, 80-6T-104.
4. "Diesel & Gasturbine Worldwide Catalog," 1980.
5. Marks' Standard Handbook for ME, Seventh Edition, McGraw-Hill, 1967.
6. "Standards Support and Environmental Impact Statement, Vol. I, Proposed Standards of Performance for Stationary Gas Turbines." EPA-450/2-77-017a.
7. "Marine Gas Turbine Applications Manual Economic Analysis Vol. III," COM-75-11196, June 75.
8. "Waste Automotive Lubricating Oil Reuse as a Fuel," EPA-600/5-74-032.

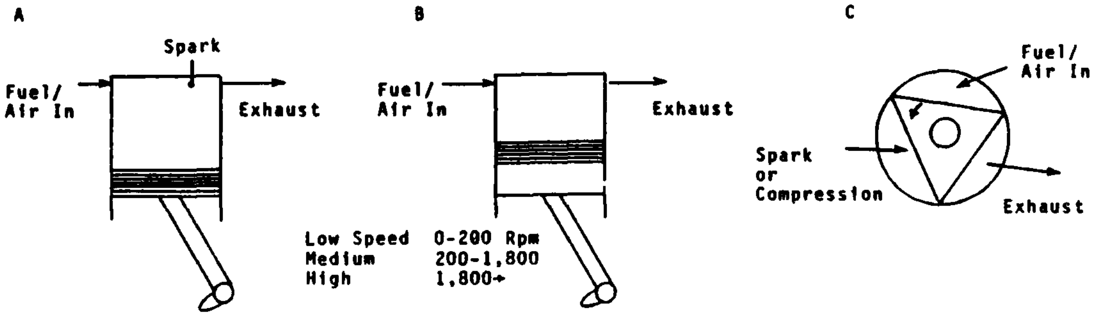
COMPONENT DESCRIPTION

IC Engines

Types: Diesel, Otto Cycle, Rotary

Types Used Commercially: Diesel, Otto Cycle

Physical Characteristics



General Description

Diesel and Otto Cycle engines consist of varying numbers of cylinders in line, or opposed. Systems consist of a carburetor, valves, cam(s), crank shaft(s), injector nozzles, combustion chamber, moving piston in a cylinder. Rotary (c) consists of rotor, cam(s), crank shaft(s), valves and injection nozzles, and spark plugs.

Principal of Operation

Fuel/air mixtures (adjusted by carburetor) enters on intake stroke, is compressed, ignited by the compression or by spark. The expanding combustion gases work on the piston. Final stroke scavenges exhaust gases Rotary intakes air/fuel, compresses it, ignites it with a spark, the gases force the rotor to turn, and finally scavenges the exhaust.

Materials of Construction

All types: block is cast from steel or aluminum. Valves and pistons are temperature, corrosion, and stress tolerant steels.

Advantages Over Other Types

Internal combustion engines, especially diesels, are the most efficient liquid fuel burners, small enough for prime movers, easily applied to electric generation. Lots of research being done, many manufacturers.

SIZING CRITERIA

Size of engine (typical): 40,000 diesel burning 0.10% mix would burn about 20 tpd. (40,000 hp)(0.40)(lb/hp/hr)(24 hr/day)(1 ton/2,000 lb)(0.1 mix ratio) = 20 tpd.

ACCESSORY COMPONENTS

Waste fuel clean-up system - filters, strainers, coalescers, purifiers, etc. Some combination of these will treat the waste oil. Pre-combustion chamber increases fuel's flexibility. Must be included in original engine, cannot be modified.

SUPPORT REQUIREMENTS

Personnel: Diesels can be run automatically after startup.

Training: Mechanic.

Skills Required: None for operation.

Inspections: Cylinder, valve wear, emissions check annually or as needed.

Access: Maintenance.

Spare Parts: Available with support from engine manufacturer.

Permits: Must meet EPA standards.

Operational Considerations

General: Fuel composition should be monitored for maintenance.

Installation: Can be on mobile beds or permanent installation.

Maintenance: Routine maintenance depending on duty cycle.

Controls: Temperature monitors output. Automatic.

Downtime: Can utilize backups or standbys or increase loads.

SAFETY AND ENVIRONMENTAL CONSIDERATIONS

General: Units should be insulated or away from working environments to control noise. Exhausted in well ventilated area.

Fire Hazard: Exhaust temperatures to 500°F. Should be kept clear of combustibles. Fuels are highly volatile. Leaks are a fire hazard. Safe (floating head) needed for storage tanks.

Explosion: IC engines do not explode. Overspeed governor possible asset.

Other Safety: IC engines are safe. Minimal safety requirements.

General Environment: Air pollution considerations, NOx, COx, SOx, etc. will increase with the dirtier waste fuels.

COST ANALYSIS

See graph on Page 4.

STATE-OF-THE-ART

R&D Needs: Combustion research to burn dirtier fuels. Air pollution increases with dirtier fuels.

Operating Systems: U.S. Coast Guard waste oil burnoff in diesel engines and boilers using a 10% mix. Coors Beer Company using a filtered 3% mix with diesel. Kroger Company, Cincinnati, operating on a filtered 5% mix.

Manufacturers: Major engine manufacturers.

Risks: Air pollution trends with waste fuels may be a problem.

Other Information: Slower speed designs have the largest capacity to burn waste and mixed fuels. Wear becomes more pronounced in higher speed models.

History: Major engine manufacturers had tested burnability of waste oil in the early fifties. Recent resurgence has resulted from dwindling supplies of regular petroleum products. Several recent tests have been made.

Successes: Engines have been proven adaptable, are mobile and have the ability to burn a wide variety of fuels with proper adjustment. Shown to be able to use up to 10% lube oil mixed with diesel. This test indicated no short-term effects. Recommendations are waste fuel to normal fuel ratios 1:100, 5:100 max for no adverse effects.

Failures: No information available.

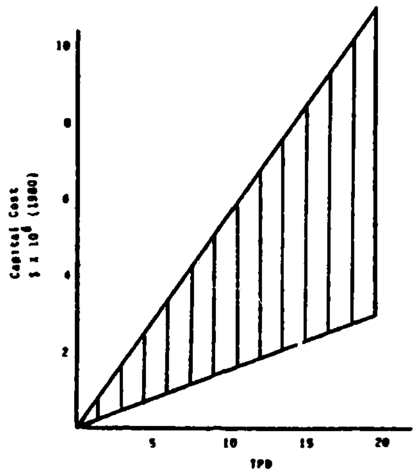
Key Problems: The technology is available to solve most of the problems associated with burning any type of fuel. Fuel treatment is also economically justifiable. The waste oils contain large quantities of trace metals, which adversely effect performance, emissions, and wear. Manufacturers endorse the mixing up to 5:100 ratios. Further mixing rates would require treatment.

Comments: The waste-derived oil properties have to be determined. The oil may or may not be capable of being fired directly. With an analysis of the properties, the mixing requirements can be determined. Filtering, cleanup systems may be purchased, for bulk waste oil treatment, then the oil may be distributed. The waste oil, when cleaned, is suitable for low mixture rates in existing engines. The engines are not very fuel tolerant. May cause reliability and availability problems for the Navy.

REFERENCES

1. Internal Combustion Engines, Obert, E. F., Harper & Row, 1978.
2. "Marks Handbook for Mechanical Engineering," 1978.
3. "The Burn-Off of Waste Oils in Coast Guard Power Plants," R. A. Walter, NTIS Report #G6-D-113-76.

4. * "Economic Comparison of Various Marine Power Plants," Femenia, SNAME Paper, November 15-17, 1973. *Represents limiting case (cost).
5. "Waste Automotive Lubricating Oil Reuse as a Fuel," EPA-600/5-74-032, September 74.



* Based on 0.34 lb/hp/hr SFc, 10% waste oil mix with regular fuel. Equipment is usually available.

Maintenance costs run around $9/kw/year. Supplemental fuel costs to burn 10 tons/day = $22k/day.

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COMFLTAIR SCE (Code 321) Atsugi JA
COMNAVLOGPAC SCE, Pearl Harbor HI
COMNAVMARIANAS Code N4, Guam
COMNAVSUPPFORANTARCTICA PWO
COMOCEANSYSPAC SCE, Pearl Harbor HI
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DEFENSE ELEC SUP CEN PWO, Dayton OH
DNL Washington DC
DOD Staff Spec. Chem. Tech. Washington DC
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MARINE CORPS BASE Code 4.01 (Asst Chief Engr) Camp Pendleton, CA; Code 406, Camp Lejeune, NC; Maint Off Camp Pendleton, CA; PWD - Engr Div Dir, Camp LeJeune, NC; PWO, Camp Pendleton CA; PWO, Camp S. D. Butler, Kawasaki Japan

MCAS Code 44, Cherry Point NC; Facil. Engr. Div. Cherry Point NC; CO, Kaneohe Bay HI; Code 1JF El Toro, Santa Ana, CA; Code S4, Quantico VA; PW Inspection Branch, El Toro, Santa Ana CA; PWO, Iwakuni, Japan; PWO, Yuma AZ

MCLB PWO, Barstow CA

NAF PWD - Engr Div, Atsugi, Japan; PWO, Atsugi Japan; PWO, Mount Clemens MI

NAS Asst PWO, Glenview, IL; Code 114, Alameda CA; Code 183 (Fac. Plan BR MGR); Code 183, Jacksonville FL; Code 183P (J. Howald), Corpus Christi TX; Code 187, Jacksonville FL; Code 18700, Brunswick ME; Code 70, Atlanta, Marietta GA; Code 8E, Patuxent Riv., MD; Dir of Engrng, PWD, Corpus Christi, TX; Engr Div Dir, Meridian MS; Lakehurst, NJ; PWD - Engr Div Dir, Millington, TN; PWD - Engr Div, Kingsville, TX; PWD - Engr Div, Oak Harbor, WA; PWD, Willow Grove PA; PWO (Code 18.2), Bermuda; PWO Belle Chasse, LA; PWO Chase Field Beeville, TX; PWO Jacksonville, FL; PWO Key West FL; PWO Lakehurst, NJ; PWO Patuxent River MD; PWO Point Mugu, CA; PWO Sigonella Sicily; PWO Whidbey Is, Oak Harbor WA; PWO Whiting Fld, Milton FL; PWO, Aux Fallon, NV; PWO, Cecil Field FL; PWO, Corpus Christi TX; PWO, Dallas TX; PWO, Kingsville TX; PWO, Millington TN; PWO, Miramar, San Diego CA; PWO, Oceana, Virginia Bch VA; PWO, So. Weymouth MA; ROICC Key West FL; SCE Norfolk, VA; SCE Norfolk, VA; SCE Pensacola, FL; SCE, Barbers Point HI

NATL ACADEMY OF SCIENCES R S Shane (Nat'l Matl Adv Bd) Springfield, VA

NATL BUREAU OF STANDARDS Demolski Washington, DC

NATL RESEARCH COUNCIL Naval Studies Board, Washington DC

NAVACT PWO, London UK

NAVACTDET PWO, Holy Lock UK

NAVADMINCOM PWO Code 50, Orlando FL

NAVAIRDEVCEN OIC/ROICC, Warminster PA

NAVAIRPROPTESTCEN CO, Trenton, NJ

NAVAVIONICFAC PWD Deputy Dir. D/701, Indianapolis, IN

NAVCOASTSYSCEN Library Panama City, FL; PWO Panama City, FL

NAVCOMMAREAMSTRSTA PWO, Norfolk VA; SCE, Wahiawa HI

NAVCOMMSTA Code 401 Nea Makri, Greece; Library, Diego Garcia Island; OICC, Nea Makri Greece; PWO Nea Makri, Greece

NAVDET PWO, Souda Bay Crete

NAVEDTRAPRODEVCEN Technical Library, Pensacola, FL

NAVEDUTRACEN Engr Dept (Code 42) Newport, RI; PWO Newport RI

NAVELEXSYSCOM Code ELEX 103 NAVFACENGCOORD, Washington, DC

NAVFAC CO (Code N67), Argentia Newfoundland; PWO Pacific Beach WA; PWO, Antigua; PWO, Brawdy Wales UK; PWO, Centerville Bch, Ferndale CA; PWO, Coos Head, Charleston OR; PWO, Point Sur, Big Sur CA

NAVFACENGCOM Code 03 Alexandria, VA; Code 03T (Essoglou) Alexandria, VA; Code 043 Alexandria, VA; Code 0432A (Andersen) Alexandria, VA; Code 044 Alexandria, VA; Code 0451 (P W Brewer) Alexandria, Va; Code 0454B Alexandria, Va; Code 04A1 Alexandria, VA; Code 04B3 Alexandria, VA; Code 051A Alexandria, VA; Code 09M54, Technical Library, Alexandria, VA; Code 100 Alexandria, VA; Code 103B; Code 1113, Alexandria, VA; Code 111A Alexandria, VA; Morrison Yap, Caroline Is.; OICC Field Office Ponape, ECI; OICC Field Office Ponape, ECI; ROICC Code 495 Portsmouth VA; code 08T Alexandria, VA

NAVFACENGCOM - CHES DIV. Code 101 Wash, DC; Code 406 Washington DC; Library, Washington, D.C.

NAVFACENGCOM - LANT DIV. Code 111, Norfolk, VA; Code 403, Norfolk, VA; Code 405 Civil Engr BR Norfolk VA; Eur. BR Deputy Dir, Naples Italy; Library, Norfolk, VA; RDT&ELO 102A, Norfolk, VA

NAVFACENGCOM - NORTH DIV. (Boretsky) Philadelphia, PA; Asst. Dir., Great Lakes IL; Code 04 Philadelphia, PA; Code 09P Philadelphia PA; Code 1028, RDT&ELO, Philadelphia PA; Code 11, Phila PA; Code 111 Philadelphia, PA; Code 114 (A. Rhoads); Library, Philadelphia, PA; ROICC, Contracts, Crane IN

NAVFACENGCOM - PAC DIV. (Kyi) Code 101, Pearl Harbor, HI; CODE 09P PEARL HARBOR HI; Code 402, RDT&E, Pearl Harbor HI; Commander, Pearl Harbor, HI; Library, Pearl Harbor, HI

NAVFACENGCOM - SOUTH DIV. CO, Charleston SC; Code 406 Charleston, SC; Code 90, RDT&ELO, Charleston SC; Library, Charleston, SC

NAVFACENGCOM - WEST DIV. AROICC, Contracts, Twentynine Palms CA; Asst Dir, San Diego Branch; Code 04B San Bruno, CA; Code 101.6 San Bruno, CA; Code 1121 San Bruno, CA; Code 114C, San Diego CA; Code 405 Civil Engr BR San Bruno CA; Code 405 San Bruno, CA; Contracts, AROICC, Lemoore CA; Library, San Bruno, CA; O9P/20 San Bruno, CA; RDT&ELO Code 2011 San Bruno, CA; Seattle Br. Dir., Seattle WA

NAVFACENGCOM CONTRACT AROICC NAS, Moffett Field, CA; AROICC, Adak, AK; AROICC, Code 1042.2, Vallejo CA; AROICC, NAVSTA Brooklyn, NY; AROICC, Point Mugu CA; AROICC, Quantico, VA; AROICC, Whidbey Is. Oak Harbor, WA; Dir, Eng. Div., Exmouth, Australia; Dir. of Constr, Tupman, CA; Eng Div dir, Southwest Pac, Manila, PI; OICC Mid Pacific, Pearl Harbor HI; OICC Trident,

Alexandria VA; OICC, Guam; OICC, Madrid, Spain; OICC-ROICC, NAS Oceana, Virginia Beach, VA; OICC/ROICC, Balboa Panama Canal; OICC/ROICC, MCAS, Cherry Point, NC; R40 AROICC Puget Sound Shpyd; ROICC AF Guam; ROICC, Keflavik, Iceland; ROICC, NAS, Corpus Christi, TX; ROICC, Pacific, San Bruno CA; ROICC-OICC-SPA, Norfolk, VA

NAVFORCARIB Commander (N42), Puerto Rico

NAVMAG SCE, Subic Bay, R.P.

NAVMEDRSCHU 3 PWO, Cairo U.A.R

NAVOCEANSYSCEN Code 4473B (Tech Lib) San Diego, CA

NAVORDMISTESTFAC Fac Supp Div, White Sands Missile Range, NM

NAVORDSTA PWO, Louisville KY

NAVPGSCOL PWO Monterey CA

NAVPHIBASE CO, ACB 2 Norfolk, VA; OICC/ROICC, Norfolk, VA; PWO Norfolk, VA; SCE Coronado, SD,CA

NAVRADSTA PWO Jim Creek, Oso WA

NAVREGMEDCEN Chief, PW Service Philadelphia, PA; PWO - Engr Div, Camp Lejeune, NC; PWO Newport RI; PWO, Camp Lejeune NC

NAVSCOLCECOFF C35 Port Hueneme, CA

NAVSCSOL PWO, Athens GA

NAVSECGRUACT PWO Winter Harbor ME; PWO, Adak AK; PWO, Skaggs Is, Sonoma CA; PWO, Torri Sta, Okinawa

NAVSHIPYD Code 106 Portsmouth, VA; Code 202.4, Long Beach CA; Code 202.5 (Library) Puget Sound, Bremerton WA; Code 380, Portsmouth, VA; Code 382.3, Pearl Harbor, HI; Code 400, Puget Sound; Code 440 Portsmouth NH; Code 440, Norfolk; L.D. Vivian; LTJG R. Lloyd, Vallejo CA; PW Dept, Long Beach, CA; PWD (Code 420) Dir Portsmouth, VA; PWD - Utilities Supt, Code 903, Long Beach, CA; PWO Charleston Naval Shipyard, Charleston SC; PWO, Bremerton, WA; PWO, Mare Is.; PWO, Portsmouth NH; PWO, Puget Sound; Tech Library, Vallejo, CA; Utilities & Energy Cons. Mgr Code 108.1, Pearl Harbor, HI

NAVSTA Adak, AK; Code 4, 12 Marine Corps Dist, Treasure Is., San Francisco CA; Dir Engr Div, PWD, Mayport FL; Engr. Dir., Rota Spain; Maintenance Div., Rota, Spain; PWD - Engr Dept, Adak, AK; PWD - Engr Div, Midway Is.; PWO, Adak, AK; PWO, Brooklyn NY; PWO, Keflavik Iceland; PWO, Mayport FL; SCE, Pearl Harbor HI; SCE, San Diego CA

NAVSUBASE ENS S. Dove, Groton, CT

NAVSUPPACT SCE, Mare Is., Vallejo CA

NAVSUPPFAC PWD - Maint. Control Div, Thurmont, MD; PWO, Thurmont MD

NAVSURFWPNCEN PWO, Dahlgren VA; PWO, White Oak, Silver Spring, MD

NAVUSEAWARENGSTA PWO, Keyport WA

NAVWARCOL Dir. of Facil., Newport RI

NAVWPNCEN Code 2636 China Lake; Code 3803 China Lake, CA; PWO (Code 266) China Lake, CA; ROICC, Code 7002, China Lake CA

NAVWPNSTA Code 092, Colts Neck NJ; Code 092, Concord CA; Engrng Div, PWD Yorktown, VA

NAVWPNSTA PW Office Yorktown, VA

NAVWPNSTA PWD - Maint. Control Div., Concord, CA; PWO Colts Neck, NJ; PWO, Charleston, SC; PWO, Seal Beach CA

NAVWPNSUPPCEN Code 09 Crane IN

NSC SCE, Charleston, SC

NCBC Code 15, Port Hueneme CA; Code 155, Port Hueneme CA; Code 156, Port Hueneme, CA; Code 25111 Port Hueneme, CA; NEESA Code 252 (P Winters) Port Hueneme, CA; PWO (Code 80) Port Hueneme, CA; PWO Gulfport, MS; PWO, Davisville RI; Port Hueneme CA

NMCB 1, CO

NOAA Library Rockville, MD

NRL Code 5800 Washington, DC

NSC Code 703 (J. Gammon) Pearl Harbor, HI; SCE (Code 70), Oakland CA

NSD PWD - Engr Div, Guam

NSWSES Code 0150 Port Hueneme, CA

NTIS Lehmann, Springfield, VA

NUSC PWO Newport, RI

OFFICE SECRETARY OF DEFENSE ASD (H&E) Pentagon (Director Categorical Programs), Washing; DASD (I&H) IC Pentagon; OASD (MRA&L) Dir. of Energy, Pentagon, Washington, DC

ONR Code 700F Arlington VA; LCDR Williams, Boston, MA

PACMISRANFAC HI Area Bkg Sands, PWO Kekaha, Kauai, HI

PWC CO Norfolk, VA; CO Yokosuka, Japan; CO, (Code 10), Oakland, CA; CO, Pearl Harbor HI; CO, San Diego CA; CO, Subic Bay, R.P.; Code 10, Great Lakes, IL; Code 101, San Diego, CA; Code 105 Oakland, CA; Code 110, Great Lakes, IL; Code 110, Oakland, CA; Code 120, Oakland CA; Code 120, San Diego CA; Code 120C, (Library) San Diego, CA; Code 154, Great Lakes, IL; Code 240, Subic Bay, R.P.; Code 30V, Norfolk, VA; Code 400, Great Lakes, IL; Code 400, Pearl Harbor, HI; Commanding Officer, Guam;

Code 505A Oakland, CA; Library, Guam; Library, Norfolk, VA; Library, Oakland, CA; Library, Pearl Harbor, HI; Library, Pensacola, FL; Library, Subic Bay, R.P.; Library, Yokosuka JA; Maint. Control Dept (R. Fujii) Pearl Harbor, HI; Util Dept (R Pascua) Pearl Harbor, HI
SCS ENGINEER Long Beach, CA
SPCC PWO (Code 120) Mechanicsburg PA
SUPANX PWO, Williamsburg VA
AF HQ USAFE/DEE, Ramstein GE
US FORCES, JAPAN Environmental Coordinator Yokota AB; Nakahara Honshu
USDA Forest Products Lab, Madison WI; Forest Service, Bowers, Atlanta, GA
USNA Ch. Mech. Engr. Dept Annapolis MD; ENGRNG Div, PWD, Annapolis MD; Energy-Environ Study Grp, Annapolis, MD; Environ. Prot. R&D Prog. (J. Williams), Annapolis MD; NAVSYSENGR Dept, Annapolis, MD; PWO Annapolis MD
ALABAMA ENERGY MGT BOARD Montgomery, AL
ARIZONA State Energy Programs Off., Phoenix AZ
CALIFORNIA STATE UNIVERSITY LONG BEACH, CA (CHELAPATI)
COLORADO STATE UNIV., FOOTHILL CAMPUS Fort Collins (Nelson)
DAMES & MOORE LIBRARY LOS ANGELES, CA
HAWAII STATE DEPT OF PLAN. & ECON DEV. Honolulu HI (Tech Info Ctr)
ILLINOIS Pollution Control Bd, Chicago, IL
KEENE STATE COLLEGE Keene NH (Cunningham)
LOUISIANA DIV NATURAL RESOURCES & ENERGY Div Of R&D, Baton Rouge, LA
MAINE OFFICE OF ENERGY RESOURCES Augusta, ME
MISSOURI ENERGY AGENCY Jefferson City MO
MIT Cambridge MA
MONTANA ENERGY OFFICE Anderson, Helena, MT
NATURAL ENERGY LAB Library, Honolulu, HI
NEW HAMPSHIRE Concord NH (Governor's Council on Energy)
NYS EMERGENCY FUEL OFFICE Albany NY (Butler)
NYS ENERGY OFFICE Albany, NY; Library, Albany NY
NYS ENERGY R&D AUTH Albany, NY
PURDUE UNIVERSITY Lafayette, IN (CE Engr. Lib)
CONNECTICUT Hartford CT (Dept of Plan. & Energy Policy)
SOUTH DAKOTA ENERGY Off of Energy Policy (Wegman) Pierre SD
STATE OF CALIF. Solid Waste Mgmnt Bd Sacramento, CA
STATE UNIV. OF NEW YORK Buffalo, NY
TENNESSEE ENERGY AUTHORITY Nashville, TN
UNIVERSITY OF CALIFORNIA Energy Engineer, Davis CA
UNIVERSITY OF ILLINOIS URBANA, IL (LIBRARY)
UNIVERSITY OF MASSACHUSETTS (Heronemus), ME Dept, Amherst, MA
VENTURA COUNTY PWA (Brownie) Ventura, CA; Plan Div (Francis) Ventura, CA
AUSTRALIA Alno, USA Meradcom Ft. Belvoir, VA
CHEMED CORP Lake Zurich IL (Dearborn Chem. Div.Lib.)
FORD, BACON & DAVIS, INC. New York (Library)
MIDLAND-ROSS CORP. TOLEDO, OH (RINKER)
POTOMAC ENERGY GRU (Naismith) Alexandria, Va
RAYMOND INTERNATIONAL INC. E Colle Soil Tech Dept, Pennsauken, NJ
3 M Technical Library, St. Paul, MN
TEXTRON INC BUFFALO, NY (RESEARCH CENTER LIB.)
UNITED KINGDOM LNO, USA Meradcom, Fort Belvoir, VA
UNITED TECHNOLOGIES Windsor Locks CT (Hamilton Std Div., Library)
WESTINGHOUSE ELECTRIC CORP. Annapolis MD (Oceanic Div Lib, Bryan)
SOCHA Somers, CT
WALTZ Livermore, CA